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AN EXAMINATION OF ISSUES RELATED TO U.S. LAKE ERIE NATURAL GAS DEVELOPMENT

ARGONNE NATIONAL LABORATORY

Division of Environmental Impact Studies

Argonne, Illinois

September 1978

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AN EXAMINATION OF ISSUES RELATED TO U.S. LAKE ERIE NATURAL GAS DEVELOPMENT.

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NOTICE

The opinions, findings, conclusions, or recommendations expressed in this report are those of the authors and do not necessarily reflect the views of the U.S. Army Corps of Engineers, the U.S. Environmental Protection Agency, or any other government agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use by the federal government.

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CONTENTS

CONTENTS

CONTENTS

CONTENTS

CONTENTS

FIGURES

TABLES

TABLES

TABLES

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INTRODUCTION

Historically, relatively inexpensive and nationally plentiful supplies of clean-burning natural gas have led to wide-scale use of gas resources by industrial, commercial, and residential sectors in New York, Ohio, and Pennsylvania (tri-state region). Within the last decade, a combination of events including regionally severe winters, inflation, a complicated gas-pricing structure, and institution of a complex gas-user priority designation has resulted in periodic shortages of gas supplies to all three states. In an attempt to maintain local economies in the face of potential future curtailments and uncertain federal gas-pricing regulations, each state has examined the potential for gas from new sources. All three states border Lake Erie and are aware that Canada successfully began developing and producing natural gas from beneath the lakebed in 1956 (although the first well was drilled in Canadian waters of Lake Erie in 1913).

Interest in developing gas resources in the U.S. portion of the central and eastern basins of Lake Erie (hereinafter referred to as USLE) has varied over the past twenty years, depending on the balance of environmental, economic, and energy priorities. However, Lake Erie gas has never been viewed as the answer to natural gas supply problems by regional gas-user industries. Throughout the years, each state has maintained a moratorium on Lake Erie gas development.

The Lake serves as a source of aesthetic enjoyment and of potable and industrial water. It is also used for recreation, commercial and sport fishing, shipping, and diluting waste effluents. Realizing the immeasurable importance of Lake Erie and the entire Great Lakes system, the United States and Canada initiated a concerted effort to reverse the intolerable deterioration of Lake Erie water quality caused by industrial, municipal, and agricultural waste loading, a process that threatened the resource benefits prized by the tri-state region, Canada, and the United States. These efforts to improve Lake Erie water quality have required millions of dollars from state and federal budgets to restore and revitalize the Lake as an essential link in the Great Lakes system, the world's largest body of surface fresh water. At all levels of government, any serious attempt to consider the development of USLE natural gas has been tempered by the knowledge that, historically, the Lake's most essential resource value has centered on important uses other than energy production.

Curtailments of natural gas during the winter of 1976-1977 resulted in layoffs and unemployment in the tri-state region. These economic hardships, coupled with the successful record of Canadian Lake Erie gas development, have led to renewed interest in evaluating the costs and benefits of developing USLE gas resources. In 1977, both New York and Pennsylvania lifted existing bans on offshore drilling. The Ohio legislature allowed the ban to expire in July 1978. By these actions, the states clearly indicated that they were willing to seriously explore the potential for developing USLE gas resources. Regardless of the outcome of any state or federal initiative to establish a

natural gas development program in Lake Erie, the International Joint Commission (IJC) has recommended the prohibition of drilling in the western basin (Int. Joint Comm. 1970). Recognition of IJC policy, together with the maintenance of a strong Great Lakes preservation attitude, has resulted in the continuation of the drilling moratorium in Michigan's Lake Erie waters.

In the United States, environmental awareness, developed during the late 1960s, led to legislation, regulations, and court decisions defining a national environmental policy expressed as the National Environmental Policy Act (NEPA) of 1969. Since the U.S. Army Corps of Engineers (COE) and U.S. Environmental Protection Agency (EPA) have permit authority over certain activities necessary for the development of gas from beneath Lake Erie, they have jointly initiated an environmental assessment program, preparatory to the development and issuance of a draft Environmental Impact Statement (EIS). For an overview of COE and EPA permit authority, see pp. 75-79. The EIS will address potential benefits and adverse impacts associated with development and production of gas from beneath U.S. waters. Based on findings of the statement and information received from other federal and state agencies and interested parties during a period of formal review, COE and EPA will prepare a final EIS. The latter will contain the recommendations and conclusions pertaining to the classification of USLE natural gas development as acceptable, conditionally acceptable, or unacceptable.

This report marks the culmination of a preliminary identification and examination of issues related to USLE natural gas development. The reader is introduced to pertinent environmental characteristics of Lake Erie and to subsurface geologic features beneath USLE and adjacent land areas. A brief synopsis of the Canadian Lake Erie gas development program is presented. Also reviewed are (1) relevant natural gas economics, (2) the existing institutional framework for administering a USLE gas development program, and (3) drilling technology related to Lake Erie gas exploitation. This overview serves as a vantage point from which the reader can begin to visualize and evaluate the complex issues identified in this report.

The issues were identified through a structured selection process, and are examined in this report using a question-response format following each of the topical (economic, institutional, technological) overviews. Initially, USLE gas development feasibility reports written for New York (N.Y. State Energy Off. 1977; Lawler, Matusky & Skelly 1977), Ohio (Shafer 1977), and Pennsylvania (Knuth 1976; Pa. Dep. Health 1968) were scrutinized for identification of unresolved problems. Additionally, literature summarizing the history of Canadian Lake Erie offshore drilling (Hurd 1977; Ont. Pet. Inst. 1969; Int. Joint Comm. 1970) was reviewed and technological components described. Subsequent to the initial review of available literature, study participants defined potential areas of interaction between offshore natural gas development and production components, and existing environmental parameters and economic and institutional frameworks applicable to USLE. The Canadian Lake Erie gas development program was used as a model on which further examination of any future USLE gas development would be based.

The project staff then met with federal, state, and Canadian environmental management and energy resource development officials who had, or could have, a defined role in planning for the development of Lake Erie natural gas resources. A meeting was also organized with a spokesperson from the League

of Women Voters of Ohio as a representative public interest group with a defined viewpoint on implementation of a USLE gas development program. Finally, meetings were held with representatives of U.S. and Canadian gas development, production, and distribution industries to discuss state-of-the-art offshore drilling and production technology and gas distribution regulations. These meetings provided a forum in which information could be exchanged and issues formulated.

Based upon the literature review, communication with public interest groups and government and industry representatives, and team member expertise, questions recognizing issues related to USLE gas development were collated within economic, legal, administrative, technological, and environmental arenas. The remainder of the study focused on determining whether individual issues could be dismissed as initially inconsequential or supported as worthy of continued attention prior to evaluating the overall acceptability of a USLE drilling program. Where existing laws, regulations, policies, and/or published research did not allow for immediate dismissal or support of issues, further research and analysis was recommended.

Since this report merely identifies and examines issues prerequisite to the development of an EIS, the reader is cautioned that there are no conclusions drawn as to the ultimate impact of implementing a USLE gas development program. The results of research and analysis efforts described briefly at the end of this report are crucial to conclusions developed in the final environmental impact statement.

The study region addressed in this report is defined by U.S. waters extending eastward from a north-south boundary line between Marblehead, Ohio, and the tip of Pt. Pelee, Ontario, to Buffalo, New York--an area which corresponds roughly to the U.S portion of the central and eastern basins of Lake Erie. The inland portion of the study area includes those counties of Ohio, Pennsylvania, and New York adjacent to the Lake, from Ottawa, Ohio, to Erie, New York. This region was defined to concentrate assessment efforts to those areas where development and production activities would have direct environmental consequences. However, where appropriate, the study area was expanded to meet the needs of issue identification and examination. Examination of natural gas economics often required expansion of investigation to a state, regional, or national level. Also, many environmental parameters were examined to gain a Great Lakes watershed perspective.

LAKE ERIE OVERVIEW

Lake Erie, the southernmost of the Great Lakes, is located between 42°45' and 42°50' north latitude and 78°55' and 83°30' west longitude. The Lake is oblong in shape with its longest axis oriented at about 70° east of north. It has a total length of 386 km (240 mi), a mean width of 71 km (44 mi), and can be divided into three sub-basins (Fig. 1). The western basin is separated from the central basin by a rocky underwater rise and a chain of islands between Pt. Pelee, Ontario, and Marblehead, Ohio. A wide sandy ridge, extending from Long Point, Ontario, to Presque Isle, Pennsylvania, separates the central from the eastern basin. Much of the Lake is shallow with mean depths of 11 m (36 ft), 25 m (82 ft), and 64 m (210 ft) for the western, central, and eastern basins, respectively (Burns and Ross 1972; Sly 1976).

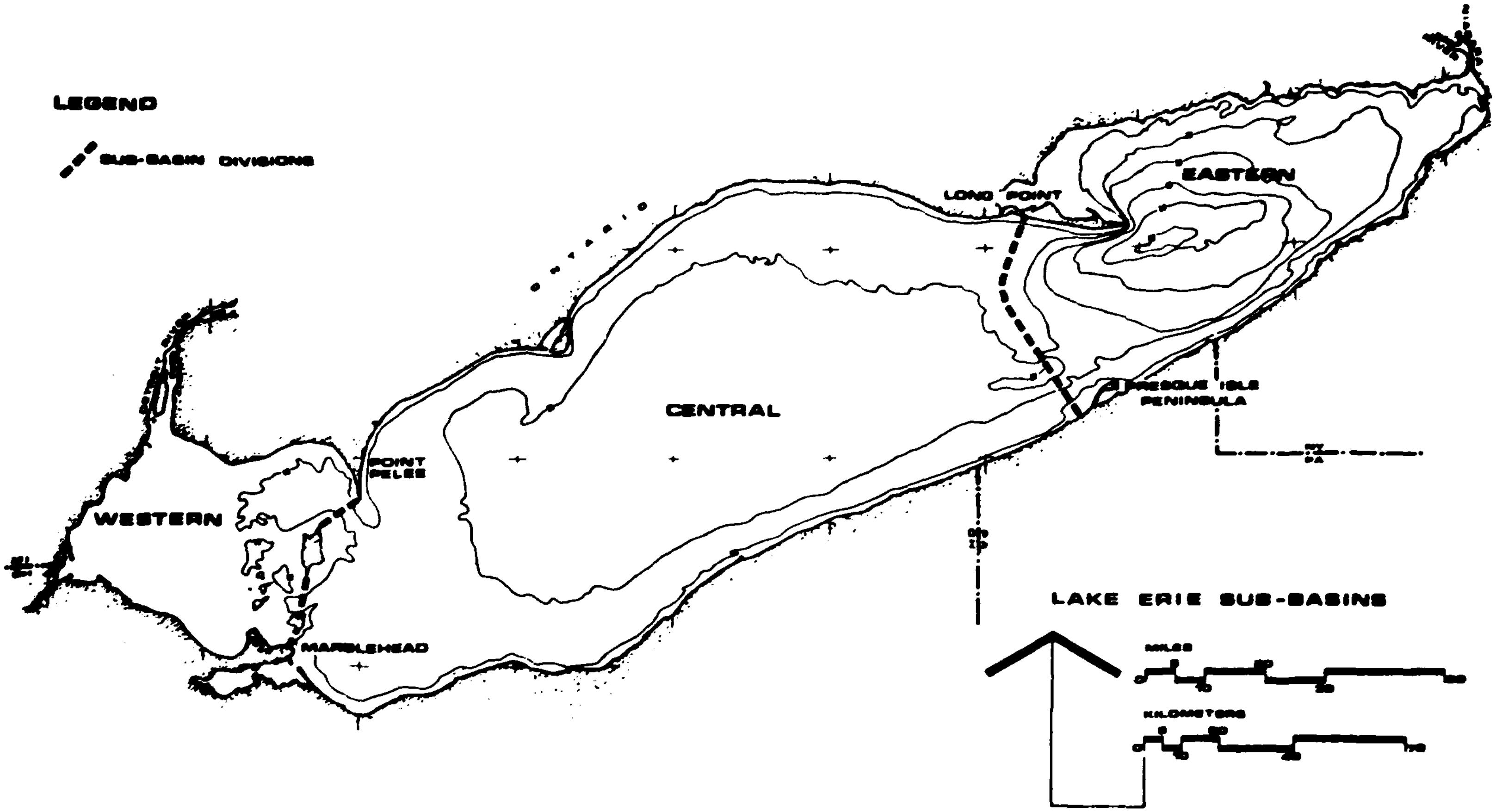

Figure 1. The Structural Sub-basins of Lake Erie. Contour intervals are 10 m (33 ft).

Historical evidence of cultural development within the Lake Erie watershed (Fig. 2) suggests that impact upon water quality was localized until the 1900s when intensive industrialization began (Sly 1976). The heavy and diversified industrial growth of the southern shore (United States) was paralleled by a slower and less broadly based agricultural development in the northern portion of the drainage basin (Canada). This led to a gradual increase in anthropogenic, atmospheric, and tributary loading, primarily from the southern shore. Today Lake Erie is utilized as a resource for a multiplicity of industrial, municipal, commercial, and recreational purposes. Since all these activities have an effect on the physical, chemical, and biological conditions of the Lake, Lake Erie water quality at any one place or time is the product of a series of complex chemical, biological, and physical interactions involving processes within and outside of the Lake. These processes may be of geologic, biogenic, anthropogenic, or atmospheric origin. Therefore, chemicals released from natural and cultural activities enter one or a combination of three media: air, water, or soil. Rarely, if ever, do materials reside very long in any one medium.

The phase association of a nutrient or contaminant with water, sediments, and biota in Lake Erie reflects its biogeochemical cycle. Spatial and temporal distribution relates to oxidation-reduction conditions, diffusion and disturbance exchanges from sinks, and physical mixing within the lake basin. Past loading of nutrients and contaminants from all sources is reflected, in part, in present biological and chemical conditions.

Contaminant Loading

The accumulation of heavy metals, other contaminants, and nutrients in Lake Erie has contributed to the degradation of water quality and to the alteration of biological communities in the Lake (Beeton 1965). Although the sources of many of these metals are natural, wastes of anthropogenic origin have greatly augmented the rate of loading. Upchurch (1972) estimated that 53 percent of the heavy metal loading to Lake Erie was anthropogenic in origin. The two major sources of this loading are effluent discharges of municipal wastes (Table 1) and industrial wastes entering Lake Erie from its tributaries (Table 2). Anthropogenic input to Lake Erie of mercury, lead, zinc, and cadmium exceeds that derived from natural weathering and atmospheric deposition (Table 3).

The western basin receives heavy metal input principally from the Detroit and Maumee rivers. Because the Detroit River is an interconnecting channel between Lakes Erie and St. Clair, the origin of some of these heavy metals is the upper Great Lakes. The city of Detroit and adjacent areas contribute heavily with industrial and municipal discharges. Walters et al. (1974) found that mercury loading to the western basin was derived primarily from two chloralkali plants, one located near Sarnia, Ontario, and the other near Wyandote, Michigan.

The distribution of heavy metals introduced into the Lake correlates with lake currents, tributary loading, and sediment deposition (Int. Joint Comm. 1978). Bottom sediments in the Lake show a varying degree of heavy metal enrichment over concentrations in the water column (Tables 4-6). Recent studies have shown that mercury concentrations (µg/kg) in the sediments of

Figure 2. Location of Lake Erie and Its Associated Watershed in the Great Lakes Drainage Basin.

Table 1. Municipal Loading of Heavy Metals to Lake Erie, 1975 to 1976[a]

Metal	Concentration (μg/L)[b]	Flow Rate (L/day)	
		Average	Range
As	<2.0 - <5.0	7.0×10^7	$1.5 \times 10^4 - 3.6 \times 10^5$
Cd	<8.0 - 18.0 (124)	6.4×10^7	$3.8 \times 10^3 - 4.5 \times 10^5$
Cr	<5.0 - 69.0 (460)	6.[illegible] $\times 10^7$	$3.8 \times 10^3 - 4.5 \times 10^5$
Cu	<5.0 - 54.0 (166)	6.4×10^7	$3.8 \times 10^3 - 4.5 \times 10^5$
Hg	<0.1 - 0.5 (0.6)	6.4×10^7	$3.8 \times 10^3 - 4.5 \times 10^5$
Ni	<2.0 - 300.0	3.9×10^7	$1.0 \times 10^4 - 4.5 \times 10^5$
Pb	<10.0 - 920.0	6.4×10^7	$3.8 \times 10^3 - 4.5 \times 10^5$
Zn	30.0 - 1400.0 (3850)	6.4×10^7	$3.8 \times 10^3 - 4.5 \times 10^5$

[a]Data from Konasewich et al. (1978).

[b]Numbers in parentheses represent the highest *influent* concentration measured.

Table 2. Concentrations of Heavy Metals in Waters of Lake Erie Tributaries[a]

River[c]	Date	No. of Samples	Concentration (μg/L)[b]										
			As	Cd	Co	Cs	Cu	Fe	Hg	Mn	Ni	Pb	Zn
Huron	1973-1977	5	2-3[d]	0.3-2	-	-	4-8[d]	-	<0.2-0.4	-	24	2-33	26-36
Raisin	1973-1977	7	2-3	0.2-2	-	-	14-16	-	<0.2	-	22-24	<1-31	20-30[d]
Maumee	1975-1977	11	-	11	10	3	3	-	-	-	82	20	21
Detroit[e]	1974	12	-	0.5	-	10.5	8.6	1240	2.7	19	20	5.7	74

[a]Sources of data: Huron, Raisin, and Maumee rivers - Konasewich et al. (1978); Detroit River - Environmental Control Technology, Inc. (1974).

[b]"Total" unless otherwise specified.

[c]Samples collected near mouth of the river, except the Maumee where samples were collected in the river basin and represent streamwater background.

[d]Dissolved fraction.

[e]Values represent average concentration of four stations.

Table 3. Natural, Anthropogenic, and Atmospheric Loading to Lake Erie[a,b]

Types/Site	Elements (metric tons/year)							
	Cd	Cl	Cu	Hg	N	P	Pb	Zn
Natural								
Eastern basin	14	-	495	0.6	46,140	9,290	370	1,600
Central basin	9	-	200	0.5	11,410	7,585	160	680
Western basin	9	-	170	0.7	7,540	4,635	215	610
Whole Lake	32	-	865	1.8	41,940	24,550	745	2,890
Anthropogenic								
Eastern basin	37	-	385	4.5	46,140	9,290	1,350	3,440
Central basin	19	-	235	5.8	30,540	4,120	725	1,660
Western basin	14	-	165	6.2	9,020	1,185	480	915
Whole Lake	70	-	785	16.5	85,700	14,595	2,555	6,015
Atmospheric								
Total Lake	150	87,000	330	-	19,000	800	2,200	909

[a]Estimates of natural and anthropogenic loading to Lake Erie were made from (1) pre-settlement (natural background) and post-settlement (post-1850) concentrations of heavy metals from sediment cores collected in the Lake, (2) analyses of geochemical and mineral species at 12 shoreline bluff locations, and (3) potential sources and dispersion pathways of lake sediments. Atmospheric loading was calculated from model and precipitation chemistry estimates.

[b]Sources of data: Natural and anthropogenic - Kemp et al. (1976); Atmospheric - International Joint Commission (1977); Cl - Upchurch (1972); Zn - Andren et al. (1977).

Table 4. Average Concentrations of Heavy Metals in the Water Column of Lake Erie[a]

Location	Concentration (μg/L)					
	Cu	Fe	Mn	Ni	Pb	Zn
Whole Lake (9 stations)	15	156	26	3	4	8
Eastern basin (3 stations)	14	76	13	2	4	10
Central basin (3 stations)	14	145	34	2	4	8
Western basin (3 stations)	17	246	31	4	4	7

[a]Data from Chawla and Chau (1969).

Table 5. Concentrations of Heavy Metals in Sediments at the Mouth of Twenty Tributaries to Lake Erie[a,b]

Metals	Concentration (μg/g) Average	Range
Ag	0.5	0.1 - 1.4
Cd	0.2	0.6 - 7.8
Co	10.0	6.6 - 14.7
Cr	29.5	3.6 - 124.5
Cu	22.0	1.5 - 69.8
Hg	283[c]	60 - 860[c]
Mn	193.1	53 - 350
Ni	20.6	4.5 - 37.2
Pb	25.4	3.3 - 90.6
Zn	79.6	15.7 - 220.8

[a]Data from Konasewich et al. (1978).

[b]Grand River (Ohio), Lynn River, Big Otter Creek, Catfish Creek, Kettle Creek, Muddy Creek, Raisin River, Maumee River, Portage River, Sandusky Bay Mouth, Huron River, Vermillion River, Black River, Rocky River, Cuyahoga River, Chagrin River, Grand River (Ontario), Ashtabula River, Conneaut River, Silver Creek.

[c]μg/kg.

Table 6. Heavy Metal Concentrations in Lake Erie Sediment Cores[a]

Location	Sediment Core Interval (cm)	As	Cd	Co	Cr	Cu	Fe	Hg	Ni	Sb	Zn
				Concentration (μg/g)							
Eastern basin (42°40', 79°20')	0-8	0.3	0	6.2	10.0	10.3	10,400	<0.1	10.0	1.1	36.3
	0-80	0.3	0	6.2	10.0	9.5	10,025	<0.1	37.5	0.9	33.5
Central basin (41°30', 82°15')	0-8	2.0	2.6	13.0	47.5	37.0	29,500	0.3	44.5	1.4	23.0
	0-50	1.4	2.1	12.3	36.5	26.0	11,500	0.2	31.8	0.9	17.8
				Enrichment Factor[b]							
Eastern basin[c]	0-80	2.6	-	1.01	1.04	1.2	0.96	3.1	0.48	3.2	1.7
Central basin[c]	0-50	5.0	2.5	1.2	4.5	4.1	1.8	6.6	5.6	3.6	3.3

[a]Data from Walters et al. (1974).

[b]Ratio of concentration in sediment to concentration in water.

[c]Average enrichment factors: eastern basin = 1.7; central basin = 3.8.

the western, central, and eastern basins were 1622 ± 694, 544 ± 191, and 483 ± 272 μg/kg, respectively (Thomas and Jaquet 1976). Of the three basins, the eastern receives the highest input of heavy metals. Additions to this basin are primarily from the city of Buffalo and from sedimentation of metals associated with fine-grained sediments carried into the basin by prevailing currents.

Loading of chlorides, sulfates, and hydrocarbons also is important to the water quality and biological integrity of the Lake (Konasewich et al. 1978). The concentration of chlorides in Lake Erie increased threefold between 1910 and 1964, from 7 μg/mL to approximately 23 μg/mL. The sources of this input were identified to be the Detroit River (27%), municipal effluents (4%), street and highway salting (11%), and industrial wastes (57%) (Ownbey and Kee 1967). Further, the annual loading of chloride to the western basin from the Detroit and Maumee rivers was calculated to be 30 × 10^8 kg/yr (66 × 10^8 lb/yr) and 1.2 × 10^8 kg/yr (2.6 × 10^8 lb/yr), respectively. Later studies indicated that between 1967 and 1977 chloride additions to the entire Lake showed a gradual decrease from approximately 3.7 × 10^9 kg/yr (8.2 × 10^9 lb/yr) to 2.6 × 10^9 kg/yr (5.7 × 10^9 lb/yr) (Konasewich et al. 1978).

Increased use of fossil fuels for industrial energy requirements has resulted in the elevation of sulfate loading, primarily through atmospheric deposition, to aquatic and terrestrial ecosystems. Acid precipitation has altered lake ecosystems through the introduction of sulfur compounds, heavy metals, and other trace elements, usually resulting in a deleterious effect to the system (Gorham 1976).

Sulfate (SO_4) loading to Lake Erie has increased since the 1800s. For the early 1960s, Upchurch (1972) reported an annual loading of 13 × 10^8 kg/yr (28.7 × 10^8 lb/yr), only 1.7 × 10^4 kg/yr (3.7 × 10^4 lb/yr) of which he attributed to weathering processes. In 1974, contributions of sulfate to the Lake from U.S. sources amounted to 4.6 × 10^8 kg/yr (10.1 × 10^8 lb/yr) and from Canadian sources to 2.0 × 10^8 kg/yr (4.4 × 10^8 lb/yr), for a total of 6.6 × 10^8 kg/yr (14.6 × 10^8 lb/yr) (Int. Joint Comm. 1977); the inputs represent 69 percent and 31 percent of the total, respectively. Of the total atmospheric deposition of sulfate in Lake Erie, 84 percent originates in the United States and 16 percent in Canada (Int. Joint Comm. 1977). This difference is probably due to prevailing southwesterly winds and to the location of industrial activity along the southern shore of the Lake. More recent studies indicate that, at present, the total loading of SO_4 to the Lake is on the order of 1.2 × 10^8 kg/yr (2.6 × 10^8 lb/yr) (Konasewich et al. 1978).

Organic hydrocarbons also may contribute to the degradation of water quality and lake ecosystems. Many persistent forms of chlorinated and other hydrocarbons, such as polychlorinated biphenyls (PCB), either remain in the water column or are concentrated in sediments, transferred through food chains, and bioaccumulated in higher trophic levels. The majority of data for hydrocarbon loadings address pesticides and other synthetic compounds.

Partitioning of synthetic organic compounds between adsorbed and dissolved phases is unique to each compound. Often synthetic organic hydrocarbons are adsorbed onto sediment particulate matter. The rate of adsorption is dependent on the ratio of adsorbent (sediment particle) surface area to mass. Synthetic organic hydrocarbons accumulate in sediments of the Lake

(Table 7). Their concentrations correspond to sedimentation rates in the Lake (highest in the western basin and lowest in the central basin) and suggest an association with the particulate matter in the water column. Considerable information regarding the transport and transformation of pesticides can be found in a recent U.S. Environmental Protection Agency (1978) publication. Little work has been done on either naturally occurring compounds or releases of petroleum products from industrial and municipal sources into Lake Erie.

Table 7. Average Concentration of Organic Contaminants in Lake Erie Sediments[a]

Location	Concentration (µg/kg)			
	PCB	DDE	TDE	Dieldrin
Eastern basin	86	8.9	17.9	2.3
Central basin	74	7.4	18.3	1.7
Western basin	252	22.1	46.5	1.4
Total	95	8.2	18.4	1.6

[a]Data from Konasewich et al. (1978). PCB = Polychlorinated biphenyls; DDE = Dichloro-diphenyl-dichloroethylene; TDE = Dichloro-diphenyl-dichloroethane.

Whole Lake Circulation Patterns

Water movement is one factor that largely determines the spatial distribution of inert sediments and of particulate and dissolved substances in the three sub-basins. Currents in the Lake are generally variable in direction and velocity; flows outside the immediate influence of the Detroit and Niagara rivers are usually correlative with the direction and intensity of the instantaneous winds and with the fluctuations of seiches. In the western basin, the Detroit River plume extends southeastward and dominates the central area of the basin. The outflow from the basin is primarily at the northern end, between Pelee Island and Pt. Pelee, Ontario (Pelee Passage). Water movements in the interisland region are random, exhibiting little pattern or permanence in direction or speed.

The principal surface flow in the central basin is first southeast from Pelee Passage then eastward and to the right of the longitudinal axis of the Lake. This pattern exhibits a certain degree of steadiness derived from the direction of the prevailing southwesterly surface wind. During thermal stratification, surface flowage in the central basin may be four times as rapid as that at intermediate depths, and a large horizontal transport can be realized in the thin surface layer. At intermediate depths, the flow regime in the

open Lake is diffuse, though predominantly in a westerly direction near the longitudinal axis and easterly along the U.S. shoreline. Surface drift in the central basin has been estimated at 7-10 cm/s (2.8-3.9 in./s) [maximum speeds in excess of 54 cm/s (21.3 in./s) have been recorded] and bottom flow at approximately 0.6 cm/s (0.2 in./s) (Hamblin 1971; Simons 1976). Bottom currents in the central basin show either open-lake or shoreline patterns (Hamblin 1971). Movement immediately along the shore is predominantly eastward, whereas flow near the bottom of the open segment of the central basin is predominantly toward the north. Therefore, material originating on the U.S. side of the Lake and suspended near the bottom is transported toward the Canadian side. This general pattern of water movement is substantiated by drift-bottle studies and the occurrence of upwelling phenomena along the Canadian shoreline (Int. Joint Comm. 1970).

When the Lake is thermally stratified, surface currents in the eastern basin flow eastward along the longitudinal axis of the Lake with a slight deflection toward the U.S. shoreline. These currents are mainly wind-driven except within the influence of the Niagara River [6 km (3.7 mi) from the river origin] where hydraulic currents overrule. The principal portion of the Niagara River flow is drawn from the U.S. side of the basin. Bottom currents in the basin tend to flow in a direction opposite that of the prevailing wind direction and the resultant speeds for the surface and bottom currents in this basin are similar to those in the central basin (Hamblin 1971).

Sediment Loading

Lake Erie can be separated into two regions on the basis of sediment deposition characteristics: depositional regions, where fine-grained sediment accumulate, and non-depositional regions, where the bottom is scoured and composed primarily of bedrock, glacial till, glaciolacustrine clay, or sand (Fig. 3). In the depositional regions, the sediment consists of 50-75 percent clay-sized particles (<0.004 mm in diameter) and the remainder silt-sized (0.004-0.062 mm in diameter). Particle size shows a strong correlation with depth, i.e., the finest sediment is found in the deeper eastern basin, the coarsest in the western basin. Calculations for sediment loading and spatial deposition indicate that 27 percent of the annual loading of fine-grained sediments is deposited in the central basin whereas 50 percent accumulates in the eastern basin (Kemp et al. 1976). The range of annual rate of accumulation in the Lake is from 0 to 7.4 mm (Kemp et al. 1977).

Tributaries contribute heavily to the total sediment loading in Lake Erie (Table 8). However, Kemp et al. (1977) found that 40 percent of the silt- and clay-sized fraction of the total input is derived from erosion of shoreline bluffs and only 28 percent from tributaries. Their calculations suggested that of the 14.9×10^6 metric tons (MT) of fine-grained sediment entering the Lake annually, 30 percent or 4.5×10^6 MT was exported through the Niagara River. Although this suggests a net silt- and clay-sized sediment loading of 10.4×10^6 MT, the study presented a net loading of 14.3×10^6 MT. The authors postulated that the 3.9×10^6 MT discrepancy was attributable to an underestimation of the inputs.

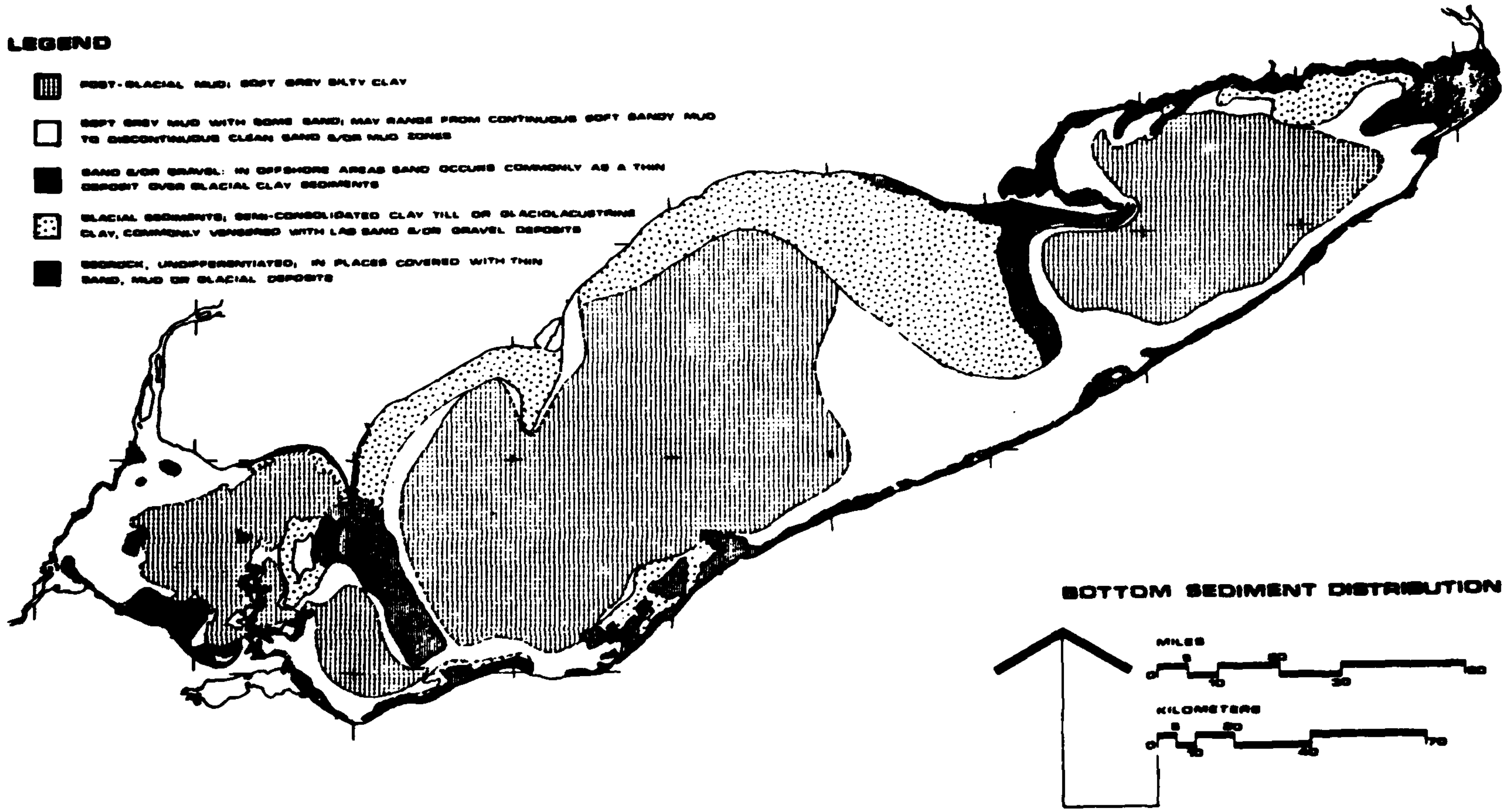

Figure 3. Bottom Sediment Distribution in Lake Erie. Data from Thomas et al. (1976).

Table 8. Annual Loading of Solids to Lake Erie from Tributaries[a]

U.S. Tributaries		Canadian Tributaries	
Source	Suspended Solids (MT/yr)	Source	Total Solids (MT/yr)
Black River	16,000	Grand River (Ontario)	893,500
St. Clair complex	13,000	Stoney Creek	21,250
Clinton River	13,000	Sandusky Creek	21,800
Rouge Complex	23,000	Nanticoke Creek	17,900
Huron River	23,000	Lynn River	34,700
Swan Creek complex	7,900	Dedrich Creek	8,780
Raisin River	150,000	Big Creek (Norfolk)	77,000
Ottawa River	54,000	Clear Creek	6,324
Maumee River	1,400,000	South Otter Creek	13,000
Toussaint-Portage	110,000	Big Otter Creek	87,420
Sandusky River	340,000	Catfish Creek	63,000
Huron-Vermillion	280,000	Kettle Creek	47,600
Black-Rocky	460,000	Talbot Creek	25,400
Cuyahoga River	630,000	Brock Creek	4,094
Chagrin complex	270,000	16 Mile Creek	7,000
Grand River (Ohio)	570,000	Muddy Creek	1,580
Ashtabula-Conneaut	240,000	Sturgeon Creek	6,100
Cattaraugus Creek	680,000	Cedar Creek	11,200
Tonawanda complex	320,000	Big Creek	9,700
		Detroit River[b]	27,800,000

[a]Sources of data: U.S. tributaries - International Joint Commission (1978); Canadian tributaries - Ongley (1976).

[b]A U.S. and Canadian boundary river. Source of data: International Joint Commission (1978).

Mechanisms Affecting Chemical Behavior of Contaminants

Physicochemical mechanisms affecting the behavior of sediment-associated contaminants such as heavy metals and organic compounds can be classed in three groups: oxidation-reduction (redox) potential in the sediments or overlying water column which would favor the release of reduced chemical constituents to overlying waters; diffusion of interstitial water across the sediment-water interface and release through bioturbation, gas bubbles, and wave- or wind-induced turbulence; and physical mixing by current action to distribute contaminants.

The offshore, fine-grained sediments in the Lake Erie sub-basins exhibit relatively similar physicochemical characteristics with the exception of redox

potential. The electromotive redox potential usually bears a close relationship to oxygen values in overlying hypolimnetic waters (Kemp et al. 1976). The top centimeter (0.4 in.) of sediment in Lake Erie normally exhibits positive redox potentials except where bottom waters in the central and eastern basins become anoxic during summer stagnation (Burns 1976). A notable exception is an extensive area with reducing conditions at the top 1.5 cm (0.6 in.) sediment depth, extending northward from the coast near Cleveland, Ohio, and then eastward along the south shore of the central basin. This plume is the result of waste input from the Cuyahoga River and Cleveland Harbor (Thomas et al. 1976).

Typical bottom sediments in the Great Lakes probably exert little influence upon the chemistry of the overlying waters so long as the oxygen concentration of the waters at the sediment surface is 1-2 μg/mL or more (Mortimer 1971). Once these waters become anoxic, many trace elements are mobilized and can be reintroduced from the sediments into overlying water. Iron, manganese, and sulfur are mobile elements and comprise more than five percent of the total sediment by weight (Kemp et al. 1976). During anoxic conditions, these elements, along with nutrients (organic carbon, nitrogen, phosphorus, etc.), can be released to the water column (Kemp et al. 1976).

Information on the associations of metals with sediments is useful in predicting the mobility of metals to the sediment interstitial waters and release during disturbance and resuspension. When sediments are disturbed, the initial release of heavy metals comes from fractions dissolved or suspended in interstitial water, followed by easily exchangeable phases associated with the sediment particles with which they are bound. The availability of contaminants to the biota in Lake Erie depends upon the chemical phase of the substance and its proximity to the biological community.

Biological Communities

The present assemblages of phytoplankton, zooplankton, benthic invertebrates, and fishes in the biotic community of Lake Erie represent an integrated response to weather, climate, contaminant concentrations, nutrient enrichment, alteration of the watershed, commercial exploitation of fish, and other factors.

According to a 1975 study (Munawar and Munawar 1975), diatoms contributed the highest percentage of total phytoplankton biomass in the western (58 percent) and central (55 percent) basins, but the lowest in the eastern basin where phytoflagellates were dominant and constituted 41 percent of total phytoplankton biomass. The phytoplankton biomass in the western basin showed a bimodal distribution, one peak during fall (8 g/m^3) and a higher one during spring (13 g/m^3); however, phytoplankton biomass in both the central and eastern basins was unimodal (6 g/m^3 and 4 g/m^3, respectively). The pattern of lower biomass maxima and less frequent phytoplankton blooms from west to east reflected the relative degree of eutrophication of each basin--decreasing from west to east (Munawar and Munawar 1975).

Historically, phytoplankton density increased from an average of 81 cells/mL in 1929 to 2423 cells/mL in 1962. Between the years 1920 and 1937, the average concentration was 410 cells/mL, whereas between 1944 and 1963 average phytoplankton densities increased by a factor of 300 percent to 1254 cells/mL

(Davis 1964). Concurrently, the dominant diatom genera *Synedra* and *Stephanodiscus*, characteristic of clean, oligotrophic waters, were replaced by the diatom *Fragelaria* and a flagellate *Cryptomonas*, both of which were more tolerant of eutrophic conditions (Munawar and Munawar 1976).

Since 1929, the abundance and species composition of crustacean zooplankton have changed in the Lake, as reflected by significant increases in the number of copepods and cladocerans and the appearance of several new species (Chandler 1940; Bradshaw 1964). Presently, the zooplankton community is alternately dominated by opportunistic species of cladocerans and cyclopoid and calanoid copepods during the course of the year. This qualitative and temporal distribution is more similar to that of a shallow, nutrient-enriched pond than to that of the upper Great Lakes. The zooplankton community structure appears to be strongly influenced by temperature and available food resources (Watson 1976).

Benthic macroinvertebrate communities of the western and central basins of Lake Erie have also undergone a significant change in both species composition and abundance. In the early 1930s, the benthos was dominated by the burrowing mayfly *Hexagenia* and some oligochaete worms (at river mouths). However, these have been replaced by tubificid oligochaetes and chironomid larvae (Carr and Hiltunen 1965). One factor influencing this change in community composition was the expansion of an anoxic stratum in the hypolimnion of the central basin in recent years. The low oxygen concentration and elevated contaminant loading also contributed to drastic changes in the biotic community of the western basin. The burrowing mayfly is now considered extinct in the western basin (Britt et al. 1977), although other, more tolerant species may be present.

The fish community of Lake Erie has also changed dramatically over the past 150 years; this is attributable to a combination of anthropogenic and environmental factors (Regier and Hartman 1973). Originally, the Lake Erie ichthyofauna was a composite of species found in the more northern, deeper Great Lakes and of those found in smaller, warmer, more southern lakes. Hence, the Lake had a combination of lake trout and whitefish (species found in deep, cold oligotrophic lakes) and of walleye and yellow perch (species found in shallower, warmer mesotrophic lakes).

Modification of the watershed woodlands, wetlands, and prairies for agricultural and industrial uses led to extensive siltation of nearshore spawning areas. Additional spawning habitats were destroyed as marshes were drained and dams built on rivers that supported spawning migrations of walleye, sturgeon, and other species (Hartman 1973). Although present spawning grounds are not well-known, bordering states consider the majority of nearshore waters to be potential spawning sites (Fig. 4).

The most significant source of change in the Lake Erie fish community has been the sequential exploitation of various species through commercial fishing; commercial fish production has been high throughout the duration of the fishery. Annual harvests from Lake Erie have often equaled or exceeded the total harvest from the other Great Lakes. From 1915 to 1969, the average annual production from Lake Erie was about 19 million kg (41.9 million lb) (Hartman 1973). Although the quantity of harvest has remained high, the quality has changed. The first species to suffer was the lake sturgeon. From 1880 to 1890, this

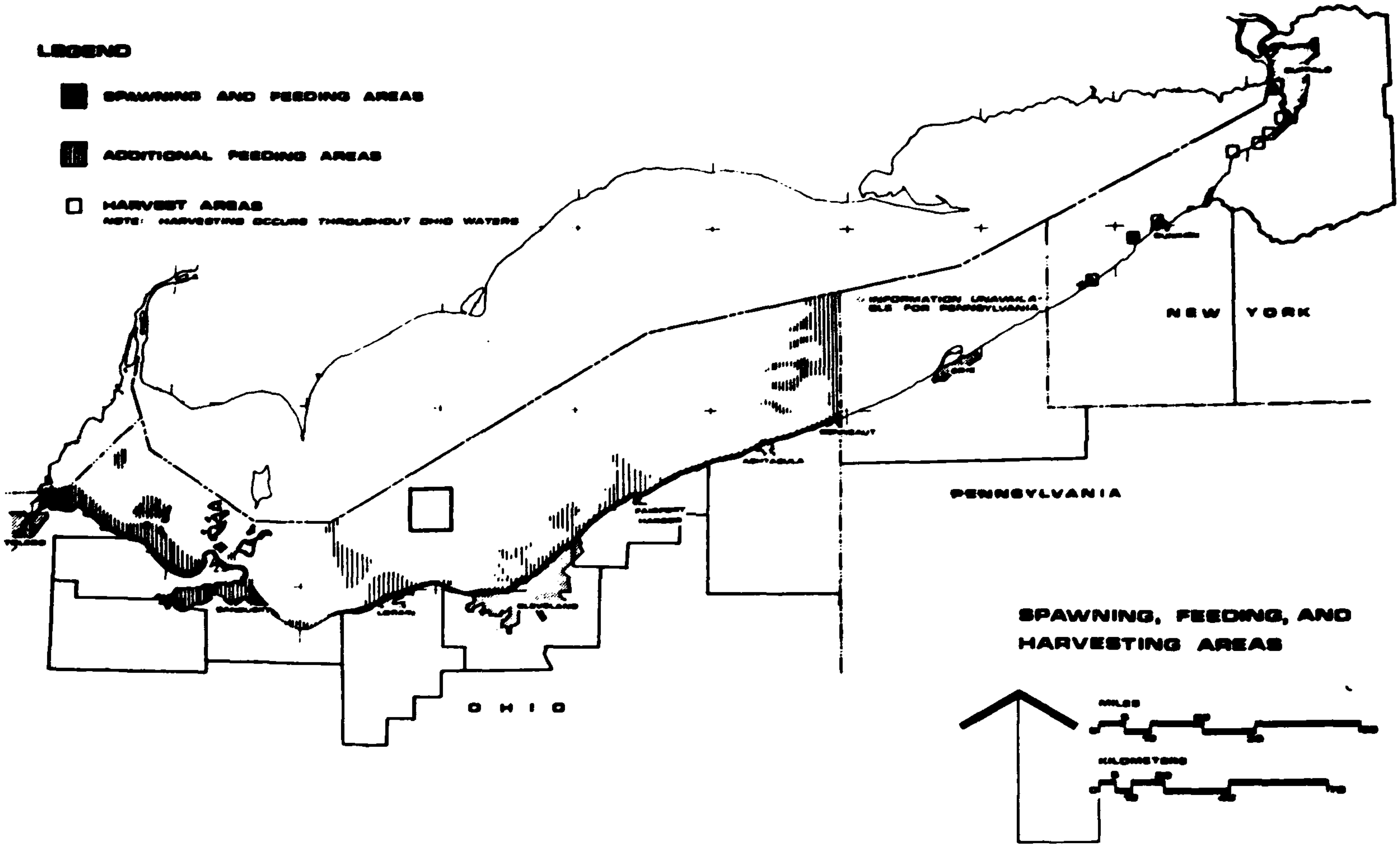

Figure 4. Spawining, Feeding, and Harvesting Areas in U.S. Lake Erie. Data from Hartley and Van Vooren (1977) and N. Y. Dep. Environ. Conservation (1977).

species was heavily exploited; the catch and population declined after 1890, and by 1900 the species was rare (Leach and Nepszy 1976). Following the decline of the sturgeon, the commercial fishery intensified for lake trout. Catches in the late 1800s exceeded 50 MT/yr, but after 1900 the species was rare and no longer important to the fishery. The sea lamprey, first recorded in the Lake in 1921, probably also had an adverse effect on the lake trout. Then the lake herring and whitefish emerged as important to the fishery. Although the lake herring or cisco was abundant in the early part of the century, between 1910 and 1925 the catch fluctuated greatly and then declined. The cisco is now considered commercially extinct (Leach and Nepszy 1976). The decline in the lake whitefish population was largely due to the combined effects of exploitation and environmental degradation, e.g., siltation of spawning areas and declining oxygen levels. Sauger and blue pike were sought next. Commercial catch for these species fluctuated from 1915 to 1958 when populations of both species declined to commercially extinct levels.

Presently, there are two stocks of walleye in the Lake, a large western basin population and a smaller eastern basin population. Little exchange has been observed between stocks. Dams and siltation greatly reduced the abundance of river spawners, but lake spawners have been successful. Harvest averaged around 825 MT/yr between 1915 and 1936, and then increased. The commercial catch for walleye increased during the 1950s and peaked at 7000 MT in 1962. Since then, production has been low. This period of decline in production and catch has been attributed to commercial fishing, environmental degradation (including reduced summer habitat due to low O_2 in the hypolimnion), and decline of food sources (e.g., the mayfly population). The walleye population in the eastern basin has been relatively stable because of low fishing pressure, good fishery management, and less dramatic changes in habitat quality (Leach and Nepszy 1976).

The present fishery in Lake Erie is based on smelt and yellow perch. Smelt were first found in the Lake in 1935 and spawning runs were established in the western basin in the early 1940s. By the early 1950s, a sizable population was established. Because of high demand for this species, harvest has remained relatively stable since the early 1960s (Leach and Nepszy 1976). Yellow perch harvest averaged 2600 MT/yr for the entire period between 1915 and 1950, but from 1930 to 1936, the time during which effort was being shifted from lake herring, the catch increased to 5700 MT. As catch of other commercial species declined in the 1950s, perch harvest increased and peaked at 15,300 MT in 1969. More recently, the catch has stabilized at around 9000 MT, approximately 25 percent of which is from the central and eastern basins.

OFFSHORE DRILLING IN LAKE ERIE

Canadian Drilling Program

History

The first offshore well on the North American continent was drilled in 1913 in the Canadian waters of Lake Erie. Two additional lake wells were completed that same year (all three by the Glenwood Natural Gas Company) as an extension to the prolific onshore Tilbury gas field (Newton 1964). Offshore gas production in the Lake remained relatively insignificant, however, as only

40 additional wells were drilled prior to 1956 (Hurd 1977). At that time, drilling activity increased, and by the end of 1977 over 1042 wells had been drilled. Some 430 wells are currently producing or awaiting hook-up to an underwater collection system that includes over 320 km (200 mi) of pipeline (Hurd and Kingston 1978). Since 1971, these wells have produced over 3.22×10^9 m^3 [113.7 billion cubic feet (BCF)] of gas at an average annual rate of 1.59×10^8 m^3 (5.6 BCF) per year (Hurd and Kingston 1978).

The original offshore drilling methods were quite crude compared to those used today. Through the 1940s, Canadian wells were drilled close to shore, from platforms atop wooden pilings driven into the Lake bottom. The platforms would remain as permanent structures when the wells were completed on their surface. When well completion was performed on the lake bottom, the pilings could be removed for use at subsequent drill sites. Steel platforms, introduced to the Lake in 1951, reduced the great cost in time and labor required to construct a wooden platform, though the latter remained in use as late as 1963 (Koepke 1964). Prior to 1965, most wells were drilled using cable-tool equipment. This drilling technique utilized a long steel bit suspended on a steel cable to crush the rock strata at the bottom of the wellbore. The bit had to be successively picked up and dropped to pulverize the rock. Periodically the bit was pulled out of the well and a bailer lowered to retrieve any water in the bottom of the hole along with most of the crushed rock or cuttings. Cable-tool drilling was generally so slow that a rig could drill only a few holes each season. A modern cable-tool rig needs only three to four weeks to complete one well (Hurd 1977). Another disadvantage of using cable-tool drilling for offshore operations is the increased risk of blowout, since drilling muds and blowout preventers cannot be used during the pulverization process (University of Texas 1951).

Rotary drilling equipment and a floating, barge-type jack-up rig imported from Louisiana were first used on Lake St. Clair in 1955 (Newton 1964). The rotary method employs a toothed or ridged cutting bit that is spun on the end of a length of pipe (drill string) suspended in the wellbore. The drill string consists of thick-walled, heavy drill collars just above the bit topped by a string of 9.1-m (30-ft) pipe sections threaded together to the surface of the hole. Rock cuttings produced by the bit are removed from the hole by pumping a drilling fluid (drilling mud, gas, or foam) down through the bore of the drill string. When the pressurized liquid, gas, or foam reaches the bit, it travels back up the outside of the drill string between the pipe and wellbore (annulus). In most offshore operations, the wellbore is supported and sealed by a pipe of larger diameter (casing) that fits around the drill string and, when cemented, tightly against the rock wall that has just been drilled. The casing pipe effectively seals off the vertical flow of liquids or gases between adjacent rock formations. When hydraulic valving equipment (blowout preventer) is placed on top of the casing, the danger from potential blowouts (unpredictable encounters with pressurized formations at the bottom of the wellbore) can be reduced. Upon detection of above-normal pressures, the blowout preventer can be quickly activated to close off the well from its surroundings.

As just described, an important advantage of rotary drilling is the increased well control. Another important advantage is the increased speed of operations (approximately five to seven days betwen rig set-up and well completion). The ability to use casing in rotary operations is an additional

benefit since it facilitates the use of auxiliary tools such as well-logging equipment and cement packers in the wellbore.

Current wells in Canadian waters are being drilled by fairly modern rotary jack-up rigs and floating drillships. Over 95 percent of the wells in the Lake are currently being drilled by four rotary units, the Timesaver II, Mr. Neil, Telesis, and Mr. Chris (Hurd 1977). The newest of the four, Mr. Chris, was built by Anschutz (Canada) Explorations Limited in 1977 (Hurd 1977).

The Timesaver II, which began drilling operations in the Lake in 1965, is a self-elevating drilling platform having a welded steel double-decked hull measuring 28 m (92 ft) long, 22 m (71 ft) wide, and 3 m (10 ft) deep. It is capable of drilling in water depths of up to 30 m (100 ft). Its six legs are arranged three to a side, each measuring 43 m (141 ft) long by 86 cm (34 in.) in diameter and having individual hexagonal-shaped pads 5 m (16 ft) across at the base (Underwater Gas Developers 1976).

In 1968, Mr. Neil was introduced to the Lake. This rig is self-propelled in addition to being self-elevating. It measures 36 m (118 ft) long by 15 m (50 ft) wide. The hull is elevated on four legs, 37 m (120 ft) long by 107 cm (42 in.) in diameter, each attached to a common rectangular mat 30 m (100 ft) long and 21 m (68 ft) wide (Underwater Gas Developers 1976). Like the Timesaver II, this rig has a maximum drilling depth capability of 30 m (100 ft).

The Telesis, a former lake freighter converted by Underwater Gas Developers Limited, began drilling in 1975. Due to its ability to drill in water depths of up to 69 m (225 ft), this vessel has an advantage over the jack-up rigs. The hull measures 79 m (259 ft) in length by 12 m (40 ft) in width and has a draft of 7 m (22 ft) (Underwater Gas Developers 1976). The vessel is moored by five 381-m (1250-ft) long, 2.8-cm (1-1/8 in.) diameter cables attached to winches in an opening in the middle of the ship (moonwell). Two 4100-kg (9000-lb) anchors are at the end of each cable. This leaves the rig free to rotate about the wellhead depending on wind and current directions. Another converted freighter, the Simcoe (later renamed the Nordrill), initiated floating drillship exploration. After a ten-year successful drilling history on Lake Erie, the Nordrill was retired in 1973.

The drilling history of these three rigs is well documented, but to date little information is available on the jack-up rig Mr. Chris.

Administrative Requirements

Rights to develop gas under the Canadian portion of the Lake are leased by Ontario's Ministry of Natural Resources. Currently, all available exploration acreage has been divided among seven operators. Two companies, the Consumers' Gas Company and Anschutz Exploration Ltd., control over 92 percent of all tracts (Hurd 1977). Before a well can be drilled, an operator must apply for a License of Occupation. Applications are accepted at the discretion of the minister, and while the license is in force, the operator has the exclusive right to drill for gas in the area designated by the license. Annual rent for a License of Occupation amounts to $94.50 (Canadian dollars) per tract. Upon the discovery of natural gas in commercial quantities, the operator may ask to have his license converted to a lease for the purposes of

production. A royalty in the amount of 10 percent of the prevailing field price is charged on gas produced, although certain deductions are allowed. Since 1971, the average royalty payable to the province has amounted to 5.4 percent (Hurd 1977).

In addition to the License of Occupation, the operator must obtain a permit to drill. Special conditions attached to this permit require notification regarding all contacts with oil. The permits specify that no drilling is allowed within a half mile of the international boundary or shoreline. A separate drilling permit must be acquired from the Canadian Federal Department of Transport in accordance with the Navigable Waters Protection Act. Waste discharges must meet the requirements of the Ontario Water Resources Act, as administered by the Ministry of Environment. Generally, the operator must ensure that wastes are disposed of in a manner not hazardous to public health or the environment. Though there has not been any single serious pollution incident during the drilling of Canadian wells to date (Hurd 1977), the Ministry of Environment has prepared a contingency plan to deal with spills of oil and hazardous substances.

Prior U.S. Drilling Activity in Lake Erie

In October 1957, the Pennsylvania Department of Forests and Waters leased two blocks of land [1.4×10^4 ha (35,710 acres)] under Lake Erie to New York Natural Gas Corporation [(NYNGC) presently known as Consolidated Natural Gas Corporation] for the purpose of offshore natural gas exploration. The drilling platform constructed by NYNGC was a jack-up rig 15.2×16.5 m (50×54 ft) with four 91-cm (36-in.) diameter legs; it was designed for a maximum water depth of 18.3 m (60 ft) (Frund 1978--personal communication). Using cable-tool equipment, two exploration holes were drilled [1154 m and 1445 m (4741 and 5098 ft) deep, respectively] to Cambrian age deposits. Both wells were unsuccessful; only non-commercial shows of gas were reported (Pa. Dep. Health 1968). The holes were subsequently plugged from top to bottom by cementing the producing zones and filling the intervening spaces with mud. A cement plug was used to the top of each hole (Frund 1978--personal communication).

Pennsylvania required that the lessee conduct water quality studies at each site while drilling was in progress. The Pennsylvania Sanitary Water Board established water quality criteria for well-drilling operations (Pa. Dep. Health 1968). The board required that oil and brines and other materials be treated before being discharged to the Lake; according to the criteria, a maximum of 15 mg/L of each could be discharged. In addition, within 91 m (100 yd) of the drilling operation, salinity, hardness, turbidity, color, odor, pH, total solids, and iron could not be increased beyond the maximum values set forth by existing U.S. Public Health Service Drinking Water Standards (U.S. Public Health Service 1946). Investigations by the Pennsylvania Department of Health indicated that the water quality criteria were not violated (Pa. Dep. Health 1968).

GEOLOGIC OVERVIEW OF THE LAKE ERIE WATERSHED

Introduction

The U.S. portion of the central and eastern basins of Lake Erie is underlain by a thin veneer of recent unconsolidated sediments (sand, silt,

clay) which in turn is underlain by sedimentary rocks ranging in age from about 450 to 375 million years; these rocks have been assigned to the Paleozoic Era. Underlying the Paleozoic strata are Precambrian (basement) rocks, consisting of granite, gneiss, and other varieties of igneous and metamorphic rock.

In the United States and Canada, oil and natural gas are produced from certain Paleozoic rocks from land-based sites around Lake Erie. In addition, gas is produced from the Paleozoic rocks beneath the Ontario portion of the Lake. As Paleozoic rocks underlying USLE are virtually certain to contain gas that can be produced, the purpose of this portion of the report is to describe these rocks and to explain the geologic conditions under which gas is being produced, on land, from the various formations. The likelihood of these conditions being repeated under USLE is evaluated to arrive at an estimate of recoverable gas reserves.

The geology of the land areas surrounding USLE has been described in numerous reports by the Ohio, New York, and Pennsylvania geological surveys, the Ontario Ministry of Natural Resources, and the Canadian Geological Survey (e.g., Clifford 1973; Kreidler 1953, 1963; Wagner 1966; Beards 1967). In addition, reports published by the U.S. Geological Survey and a number of geological journals are important sources of information concerning the geology of this region. Additional literature sources helpful in preparing this overview include Fettke (1961), Janssens (1973), Rickard (1969, 1973), and Sanford (1969).

General Stratigraphy and Structure of Paleozoic Rocks

The Paleozoic rocks beneath USLE consist of limestone, dolomite, sandstone, shale, salt (NaCl), and anhydrite. Their aggregate thickness ranges from about 1740 m (5700 ft) off Ashtabula County, Ohio, and Erie County, Pennsylvania, to about 1070 m (3500 ft) off Buffalo, New York. Generally, the thickness decreases northwestward due to thinning of individual geologic formations* and recent erosion that gouged out the area now known as Lake Erie.

The rocks of each of the seven subdivisions of the Paleozoic Era form a "System"; the time represented by each system is called a "Period" (Table 9). All but the Permian System are shown on a generalized geologic map of the land areas surrounding Lake Erie (Fig. 5). A tabular listing of geologic systems, formations, and rock types discussed in this overview is presented in Table 10.

Cambrian System

The Cambrian rocks beneath Lake Erie consist of dolomite and sandstone ranging in thickness from about 120 m (400 ft) to about 210 m (700 ft) with the thicker sections near the Ohio-Pennsylvania border.

At the base of the Cambrian System lies a sandstone (Mt. Simon or Potsdam) that has a thickness of up to about 38 m (125 ft). As this stratum directly overlies an ancient erosion surface (the top of the Precambrian rocks) that may have local relief in excess of 38 m (125 ft), the sandstone may be absent locally.

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*A *formation* is the basic geologic rock unit.

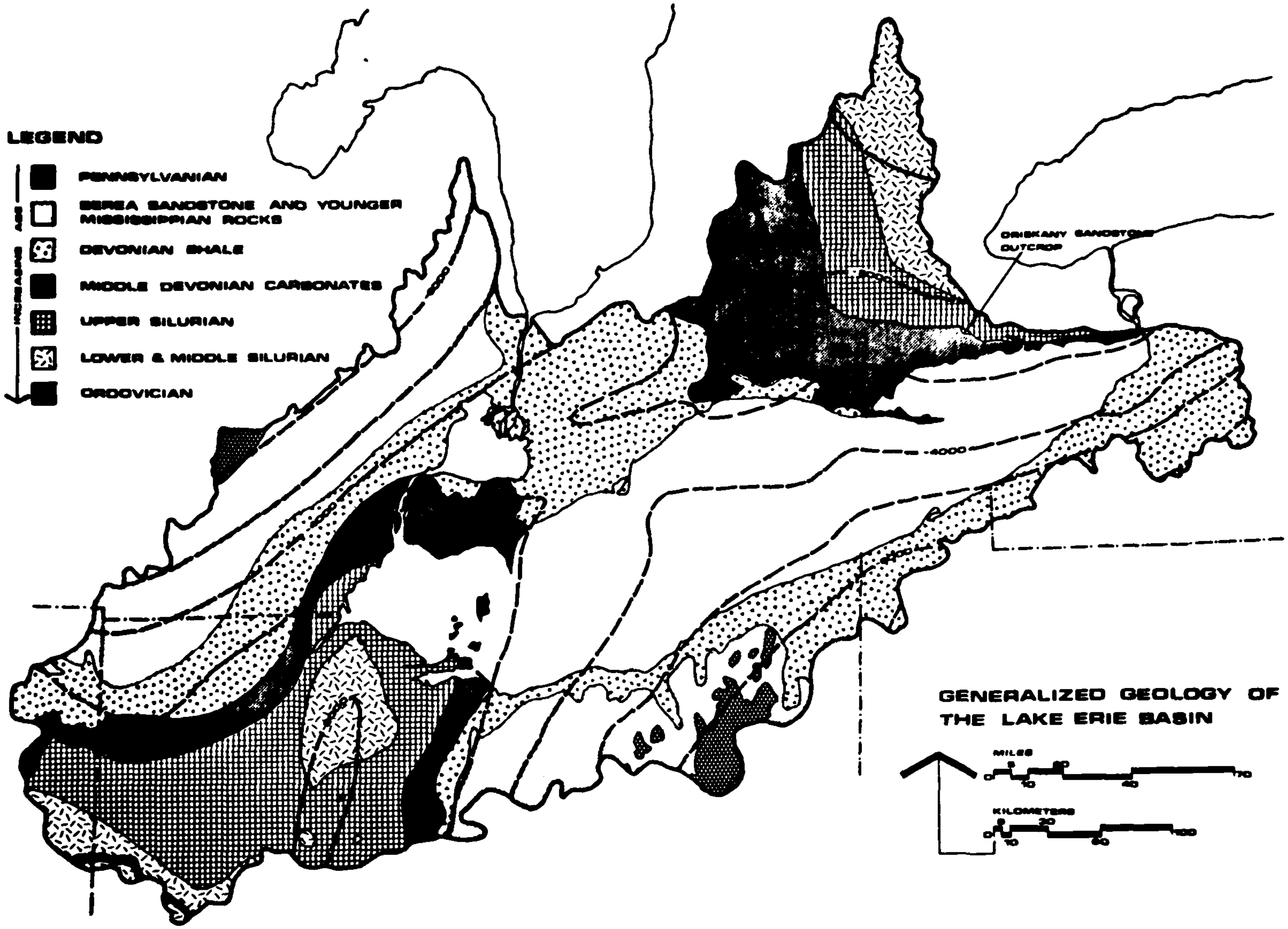

Figure 5. Generalized Bedrock Geology of the Lake Erie Basin. Dotted lines represent structural contour overlay indicating depths below sea level to the top of Precambrian rocks. Contour intervals are 305 m (1000 ft).

Table 9. Subdivisions of the Paleozoic Era

Era	System	Period
Paleozoic	Permian	Permian
	Pennsylvanian	Pennsylvanian
	Mississippian	Mississippian
	Devonian	Devonian
	Silurian	Silurian
	Ordovician	Ordovician
	Cambrian	Cambrian

Increasing age

Overlying the basal sandstone is a section consisting mostly of dolomite but containing recognizable sandstone beds in certain areas. This section extends to the top of the Cambrian System. Maximum aggregate thickness of the section will be about 175 m (575 ft). The thickness decreases northwestward, mostly because the top of the section has been truncated by pre-middle Ordovician erosion. The decreasing thickness is also due to depositional thinning and, probably, to an overlap of younger units over older ones.

Sandstone beds, which are not present beneath the land areas of this region, are likely to be found beneath the western basin of USLE. This sandstone tends to be medium- and coarse-grained and probably has adequate porosity and permeability to contain producible hydrocarbons.

In the offshore Cleveland vicinity, close to the upper boundary of the Cambrian, it is expected that there will be 15-30 m (50-100 ft) of Kerbel sandstone which, if proper trapping conditions exist, may contain producible hydrocarbons.

Locally, dolomite found at or just below the top of the Cambrian System developed secondary porosity as a result of pre-middle Ordovician erosion. Hydrocarbons are being produced from such dolomite in central Ohio and may be producible under USLE.

A regional erosion surface separates the Cambrian from the overlying Ordovician System. Known as the Knox unconformity, this surface is recognizable over wide areas of the eastern and central United States and in Ontario. The erosion, affecting the top of the Cambrian rocks, left an irregular surface characterized by hills-and-valleys topography. This surface was subsequently covered with younger rocks.

Table 10. Informal Geologic Nomenclature for Paleozoic Rocks Underlying Central and Eastern Basins of USLE

System	Subdivisions	Named Formations	Main Rock Types
Devonian	upper		shale
	middle	Onondaga Bois Blanc	limestone
		Oriskany, Springvale	sandstone
	lower	Helderberg	limestone
Silurian	upper		dolomite, anhydrite, salt, shale
	middle	Lockport	dolomite
		Rochester	shale
		Reynales-Irondequoit (Packer Shell)	limestone
	lower	Medina-Clinton (Whirlpool-Cabot Head, Grimsby, Thorold)	sandstone, shale
Ordovician	upper	Cincinnatian	shale
	middle	Trenton Black River	limestone
		Glenwood-Shadow Lake	dolomite
Cambrian			dolomite, sandstone
		Kerbel	sandstone
			dolomite, sandstone
		Mt. Simon-Potsdam	sandstone

As generally interpreted, erosion in the area of Lake Erie occurred at the end of an early part of the Ordovician Period. Early Ordovician rocks were eroded from the Lake Erie area and from Ontario. In parts of New York, Pennsylvania, and Ohio which are well to the south of the Lake, these rocks overlie, and are separated from Cambrian strata by, the Knox unconformity.

Ordovician System

Rocks of the Ordovician System in the Lake Erie region are divisible lithologically (and informally) into a middle or limestone part and an upper or shale part. To the middle limestones belong (in ascending order) a thin shaly section (Glenwood or Shadow Lake), a section of lithographic limestone (Black River limestone), and a section of presumed coarse-grained fossiliferous limestone (Trenton limestone). The upper or shale layer, generally left

undivided along the south shore of the Lake, is often called Cincinnatian shale.

The Glenwood or Shadow Lake formation consists of argillaceous and silty dolomite that may in part grade into dolomitic sandstone. In most places the formation is characterized by a greenish color. Its thickness on land varies from 0 to about 24 m (0-80 ft) but indications are that under USLE its thickness will be less than 8 m (25 ft). This formation directly overlies the pre-middle Ordovician erosion surface and, by filling the low areas on the erosion surface, tends to flatten out the relief on top of the Cambrian rocks.

The Black River limestone is made up almost entirely of lithographic limestone. In addition to minor amounts of dolomite, this limestone contains several metabentonite beds (volcanic ash) near the top of the formation. Thickness of the Black River rocks will range from about 84 m (275 ft) to about 130 m (425 ft).

The Trenton limestone consists of brown bioclastic limestone that has been dolomitized in places. In parts of southwestern Ontario the Trenton includes a shaly interval; it is not known if or to what extent this shaly section will extend under USLE. Thickness of the Trenton under USLE will range from about 30 m (100 ft) in the west to about 150 m (500 ft) in the east.

The Trenton is overlain by a thick [305-550 m (1000-1800 ft)] section of rocks whose lithology is dominantly shale, with minor amounts of limestone or dolomite and, in parts of New York, sandstone or siltstone. Along the south shore of Lake Erie these rocks have not been studied; therefore they are generally left undivided. The uppermost part of this undifferentiated shale (Cincinnatian) consists of red (because of iron-rich minerals) shale called Queenston shale. Thickness of this red shale decreases westward from New York, from about 245 m (800 ft) to less than 30 m (100 ft) near Cleveland.

Silurian System

Although the Silurian rocks consist mostly of dolomite, they do contain minor, though economically important, quantities of sandstone and salt. Additional constituent rocks are shale, anhydrite, and limestone. It is in the Silurian System that most of the natural gas below USLE is contained.

For the sake of convenience, the Silurian System is divided into three informal subdivisions, each of which will be recognizable under USLE. From oldest to youngest, these subdivisions are lower, middle, and upper Silurian.

For the purpose of this report, the lower Silurian is considered to be the rock section bounded by the Queenston shale below and by limestone or dolomite of the Reynales-Irondequoit limestones (Ontario, New York, Pennsylvania) or "Packer Shell" (Ohio) above. Under USLE the lower Silurian consists of sandstone, siltstone, and shale, except west and northwest of Lorain, Ohio, where limestone or dolomite is present instead of sandstone. It is probably from this lower Silurian sandstone that most of the natural-gas potential of USLE can be realized. Thickness of the section ranges from about 43 to 60 m (140 to 200 ft).

In the eastern portion of USLE, the lower Silurian has been subdivided in ascending order as follows: Whirlpool sandstone, Cabot Head shale and sandstone, Grimsby sandstone and shale, and Thorold sandstone. All sandstone in this area contains producible gas, though not always producible from single wells. Aggregate thickness of the sandstone is 15 m (50 ft) or less; thickness of the producing sandstone is probably less than half of the aggregate thickness in most wells.

In Ohio the lower Silurian section is generally referred to as the "Medina-Clinton." The Medina sandstone is equivalent to the Whirlpool sandstone, the Clinton sandstone to the sandstone in the Cabot Head, Grimsby, and Thorold formations.

Westward across northeastern Ohio (and across southwestern Ontario), the lower Silurian rocks thin; and west of Lorain, Ohio [and beginning about 32 km (20 mi) east of St. Thomas, Ontario], limestone or dolomite (Manitoulin or Brassfield Formation) is found instead of sandstone in the lower Silurian. Hence, west of a line extending across USLE from Lorain, Ohio, to Port Stanley, Ontario, the gas-bearing sandstone of the lower Silurian is expected to be absent.

Although the gas-bearing sandstone formations of the lower Silurian will be present over a large area under USLE and have been drilled onshore, in the area surrounding USLE the thicknesses and gas-production qualities of these formations are not uniform, but change, often significantly, from well to well. These changes include:

1. change in the thickness of a particular sandstone; the most drastic change is one in which a particular sandstone section is replaced entirely by shale
2. change in the grain size of sandstone
3. change in the proportion of siltstone and shale to sandstone
4. change in porosity and/or permeability
5. change in the hydrocarbon content of the sandstone.

As all these changes, to varying degrees, may take place within short lateral distances, exploratory drilling and developmental drilling carry a fairly significant risk that, in any particular well, the amount of producible gas will be much lower than was anticipated.

The lower Silurian sandstones have produced, and are producing, natural gas (and in a few areas some oil) along the shores of Lake Erie in southwest Ontario and east of a line between Port Stanley, Ontario, and Lorain, Ohio, in the United States. It is estimated that, in recent years, gas produced from these sandstones accounts for 90 percent of Ohio's, 65 percent of New York's, and 50 percent of Ontario's annual natural gas production.

Overlying the lower Silurian rocks is a thin [3-9 m (10-30 ft)] limestone or dolomite (with some shale) known as Packer Shell in Ohio and as Reynales-Irondequoit limestones in areas east and northeast of Ohio. This carbonate section has proven useful for structure mapping in the Ontario portion of Lake Erie and surrounding shore areas. It forms the base of the middle Silurian.

Overlying this thin carbonate is the Rochester shale (green, red, and brown shale with minor amounts of dolomite), which has a thickness across USLE ranging from about 5 m (15 ft) in the west to 30 m (100 ft) in the east.

The Rochester is overlain by as much as 107 m (350 ft) of dolomite and locally minor limestone; a number of names have been applied to this dolomite section, but for the purposes of this report these rocks will be referred to as Lockport (the name used in northwest Pennsylvania and northeast Ohio). The top of the Lockport is also the top of the middle Silurian.

The Lockport consists, with the exception of some locally occurring limestone and chert, of gray, white, and brown dolomite. The dolomite is considered to be of secondary origin, the original limestone beds having been altered to dolomite through the addition of magnesium ions that were carried through the limestone by migrating fluids. Some original limestone beds accumulated in local mounds because of profuse animal life. The animal remains (fossils) have in many cases been wholly or partially obliterated by post-depositional processes, including dolomitization. The mounds, generally known as reefs, may occur in one of two ways. They may be local and of limited vertical extent [e.g., they may be 6 m (20 ft) thick and restricted to less than 8 ha (20 acres)], or they may extend for tens of miles and encompass the entire Lockport interval; in some areas the thickness of the mounds exceeds the regional thickness of the Lockport by as much as 61 m (200 ft). The first type of mound is sometimes called a "patch reef"; the second, a "barrier reef."

Whether local or regional in extent, these reefs figure importantly in discussions of the natural gas potential of USLE because they have produced and are producing significant quantities of gas in the Ontario portion of Lake Erie (including areas west of the line marking the westward disappearance of the lower Silurian sandstone), and on the land area of southwestern Ontario and Ohio.

Locally, along the south shore of Lake Erie, a porous zone exists in the Lockport dolomite about 30-60 m (100-200 ft) above its base. Known as Newburg dolomite in Ohio, this zone will, in a number of places, contain saltwater.

The Lockport is overlain by upper Silurian rocks, which in much of USLE will consist of dolomite (with perhaps minor limestone) interbedded with anhydrite, salt, and shale. The shale, anhydrite, and salt beds are generally marker beds that can be recognized over large areas. Thickness of the upper Silurian rocks will range from about 120 to 210 m (400 to 700 ft) and will be greatest offshore Ohio. This is also the area where the aggregate thickness of salt will reach its maximum of about 46 m (150 ft). Maximum thickness of a single salt bed will be found in the same area and will be about 21 m (70 ft).

Figure 6 shows the approximate portion of Lake Erie in which bedded salt will be found at depth.

Devonian System

The Devonian System is divided into three informal subdivisions: lower, middle, and upper Devonian.

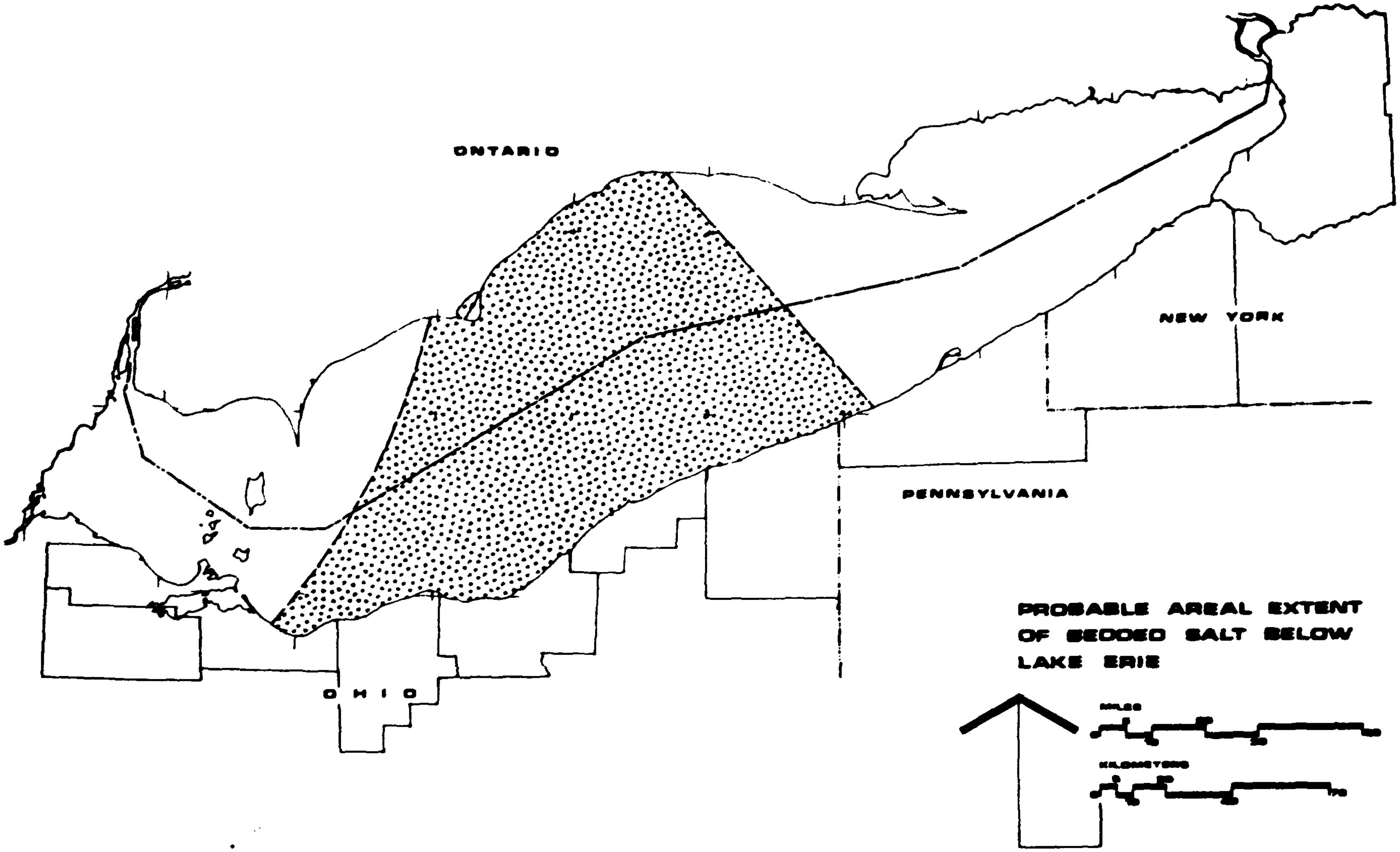

Figure 6. Probable Areal Extent of Silurian Bedded Salt below Lake Erie.

The Devonian rocks below the USLE area are separated from the underlying Silurian rocks by a regional erosion surface. The local effects of this erosion have proved difficult to map and with some exceptions may be too small to be mappable with existing well control.

The lower Devonian (Helderberg limestone) consists of up to 9 m (30 ft) of cherty and sandy limestone and is probably restricted to offshore Lake County, Ohio.

The middle Devonian rocks consist of limestone (Bois Blanc and Onondaga limestones and their equivalents) locally underlain by sandstone (Oriskany or Springvale sandstone). Oriskany sandstone is a fine- and medium-grained sandstone that will have a probable maximum thickness of 21 m (70 ft) offshore Cleveland. The sandstone is absent east of Erie County, Pennsylvania. Distribution of this sandstone in USLE will probably be irregular, and where the sandstone is absent, the base of the overlying limestone will be sandy or will contain thin sandstone beds that may be indistinguishable from Oriskany sandstone. The sandstone has produced gas in a few areas in northeastern Ohio and adjacent Pennsylvania, although most wells in this area produce saltwater when the sandstone is penetrated. Overlying the Oriskany are 45-90 m (150-300 ft) of cherty and partly dolomitic limestone (Bois Blanc and Onondaga limestones).

As used in this report, upper Devonian rocks extend from the top of the Onondaga to the base of the Berea (Mississippian) sandstone. They are the youngest rocks underlying USLE and, with minor exceptions, consist of gray, green, and brown shale. Locally they contain thin limestone and siltstone beds. Thickness of the upper Devonian section is about 400 m (1300 ft) along the south shore of Lake Erie between Cleveland, Ohio, and Dunkirk, New York, diminishing rapidly toward the northwest because of depositional thinning and the recent erosion that led to the formation of Lake Erie.

The geologic structure of USLE is characterized by a fairly uniform south-southeasterly dip of the strata. Figure I shows how the subsea depth to the top of the Precambrian basement rocks increases in this direction. Toward Lake County, Ohio, the regional dip is about 5 m/km (28 ft/mi), and toward Chautauqua County, New York, about 12 m/km (65 ft/mi). For younger rocks, these figures will be somewhat lower.

Structures analogous to those found while drilling in the surrounding land areas may be present beyond the regional dip. One type, a structural "high," can be mapped for all Paleozoic rocks. These "highs" will probably be small in extent, less than 32 ha (80 acres) and less than 15 m (50 ft) of structural closure. Another type of structural "high" affects Devonian and Silurian strata down to the salt section, but is absent below the salt beds. These structures were caused by local post-depositional thickening of salt beds (through movement), as a result of which the overlying beds are locally shaped into domes.

Seismicity

Tectonically, the Lake Erie watershed is a stable area of gently dipping beds and has, therefore, an inherently low degree of seismicity. Earthquake tremors are most likely to be felt along the New York shoreline adjacent to

the St. Lawrence Seaway, seismically a fairly active area. In addition, earthquake tremors have been felt with some frequency in the vicinity of Attica, New York [located about 48 km (30 mi) east of Buffalo]. The most severe of the recorded tremors in the Attica area occurred on 12 August 1929 when 250 chimneys were damaged (Coffman and von Hake 1973).

A geologically recent fault in this area, the Clarendon-Linden fault, has been mapped by A. M. Van Tyne (1978--personal communication). The fault runs in a northerly direction from southern Wyoming County, New York, and intersects the shoreline of Lake Ontario near the village of Troutburg, located about 80 km (50 mi) northeast of Buffalo.

A number of tremors, mostly of local extent, have been registered in the Cleveland area. One set of tremors was recorded in Lake Erie 97 km (60 mi) northeast of Cleveland; another was recorded in Fairport, along the shore in Lake County, Ohio (Coffman and von Hake 1973). The cause or origin of these tremors is not known. They may be related to readjusting movements of the earth's crust in response to the retreat of the thick ice sheets that covered this area in recent glacial (Pleistocene) times.

<u>Potential Gas Reserves under U.S. Lake Erie</u>

Some geologic formations that produce gas along the shores of Lake Erie--in parts of Ontario, New York, Pennsylvania, and Ohio--also produce gas in the Ontario portion of Lake Erie. Since it is almost certain that these producing formations extend beneath and largely across USLE, there can be little doubt that they will contain producible gas. The following questions, however, remain unanswered:

1. How large are the gas reserves under USLE?

2. Will all formations that produce gas onshore also produce in USLE?

3. In which areas under USLE are certain formations likely to produce chiefly gas, chiefly oil, or exclusively gas?

The following discussion treats those geologic formations that will or may produce hydrocarbons. Probable or possible reserves are assigned to the gas-productive formations. No estimates are made for oil reserves. A summary of reserve estimates by project staff is presented in Table 11.

Reserves are assigned to the *probable* status when geologic conditions and history of hydrocarbon production can reasonably be extrapolated from shore areas to USLE. *Possible* status is assigned to reserves from formations that have produced hydrocarbons onshore, but whose geologic and producing conditions are not known to exist under USLE with reasonable certainty.

Although a range of *reserve* estimates is provided in this section in context of the geologic structure beneath USLE, other sections of the report (see Economic Overview and Economic Issues) refer to the potential quantities of natural gas under USLE as *resource* estimates. For the purpose of economic

Table 11. Summary of Estimated Reserves under USLE

Geologic System	Formation	Reserves (BCF)[a] Probable	Possible
Devonian	Oriskany sandstone	-	25
Silurian	Lockport dolomite	-	50-300
Silurian	Lower Silurian sandstone	1,231	-
Ordovician	-	-	-
Cambrian	Dolomite and sandstone	-	25-100

[a]BCF = billions of cubic feet. To convert cubic feet to cubic meters, multiply by 0.02832.

analysis, a conservative estimate of USLE gas--resource--was derived from the range of estimates presented in this section--reserves.* Since exploration for natural gas in U.S. waters has involved the drilling of only two wells, both dry holes, estimates used in later sections are believed to conservatively indicate the, as yet, unproven extent and magnitude of gas resources beneath USLE.

Cambrian System

Significant amounts of oil and some gas have been produced from Cambrian rocks in Ohio, Ontario, and Pennsylvania. Stratigraphically, this production has been restricted to the upper portion of the Cambrian rocks (dolomite and sandstone), the reservoir generally lying less than 15 m (50 ft) below the top of the Cambrian. Hydrocarbon traps in Ontario are structurally controlled (small folds and faults). In Ohio, both stratigraphic and small structural traps are present. The trap for the modest gas production from the Cambrian System in northwestern Pennsylvania is unknown.

Most production from Cambrian rocks in Ohio and Ontario has consisted of oil; it is considered likely that this will also be true for USLE. However, in Medina County, Ohio, one gas well has produced in excess of 28.3 million m^3 (1 BCF).

Resources are defined as "concentrations of naturally occurring solid, liquid, or gaseous materials in or on the earth's crust in such form that economic extraction of a commodity is currently or potentially feasible." *Reserves* are defined as "that portion of the identified resource which can be economically extracted." [Definitions from Miller et al. (1975).]

Reservoir conditions in USLE Cambrian rocks west and north of Cleveland should be favorable for hydrocarbon production, and the possibility exists that the hydrocarbons may locally consist exclusively of gas. The Cambrian System is assigned *possible* reserves of 708 million to 2.8 billion m^3 (25-100 BCF).

Ordovician System

Rocks in the Ordovician System that have produced hydrocarbons in the vicinity of Lake Erie belong to the Trenton and Black River formations. Production, consisting almost entirely of oil, came from types of reservoirs unlikely to be found under USLE. Shows of oil have been recorded from the Trenton in Erie County, Pennsylvania. No gas reserves are assigned to the Ordovician rocks of USLE.

Silurian System

The geology and history of gas production of the shore areas of USLE make it evident that most of the probable gas reserves under USLE are contained in the Silurian rocks. These reserves are present in two stratigraphic intervals, the lower Silurian sandstones (Clinton-Medina) and the middle Silurian Lockport dolomite. Reserves in the latter are considerably more difficult to estimate than those in the former.

Calculation of probable gas reserves in the lower Silurian sandstones is based on assumptions for potential areas of natural-gas-producing land, success ratio, probable reserves, and well spacing.

Prospective gas-producing land area. Potential areas of natural-gas-producing land under USLE waters are presented in Table 12. These estimates were obtained by subtracting the area of two buffer zones (a half-mile-wide buffer adjacent to the International Boundary and a one-mile-wide buffer adjacent to the shoreline) from the total Lake Erie area of each state thought to be productive in the lower Silurian sandstones. In addition, slightly more than 13,355 ha (130 km^2) [33,000 acres (50 mi^2)] was subtracted from Ohio's producing area because it is considered likely that in this area off Ashtabula County the reservoirs contain some oil. The assumption has been made that oil production will not be allowed.

Ohio's total Lake Erie area is 913,630 ha (2,257,550 acres). Of this amount, 688,500 ha (1,700,000 acres) of Ohio land is in drillable portions (central basin) of Lake Erie. Excluding the buffer zones, Clifford (1975) assigned 526,110 ha (1,300,000 acres) to the area underlain by the lower Silurian sandstones. Clifford's figure is adopted here, except that 13,355 ha (33,000 acres) have been subtracted for the reason cited above.

Success ratio. The most reliable figure for the success ratio (the number of wells drilled, completed, and producing per every hundred wells drilled) is considered to be the ratio found in the drilling of the Ontario portion of Lake Erie, or 65 percent.

Assigned *probable* reserves. Each 2.6 km^2 (or one square mile) parcel is assigned probable reserves of 17 million m^3 (0.6 BCF).

Table 12. Potential Areas of Natural-Gas-Producing Land under USLE

State	Net Productive Land[a] (ha)	(acres)
New York	127,885	316,000
Ohio	512,755	1,267,000
Pennsylvania	176,854	437,000
Totals	817,494	2,020,000

[a]Estimates of area are approximate and reflect the deletion of lakebed areas within buffer zones adjacent to the international boundary and state shorelines.

Well spacing. It is assumed that at least initial drilling would be done with a well spacing of 2.6 km^2 (640 acres).

Calculation of estimated probable gas reserves. From these data and assumptions, the probable reserves under USLE are:

Probable reserves under USLE = net productive area × success ratio × assigned probable reserves/640 acres

$$= \frac{2,020,000 \times 0.65 \times 0.6}{640}$$

= 1231 BCF (34.9 billion m^3) from lower Silurian sandstones

The Lockport dolomite has produced considerable amounts of gas from patch and barrier reefs in a number of places in southwestern Ontario. The Tilbury field has produced in excess of 7 billion m^3 (250 BCF). In recent years, about half of Ontario's annual gas production [about 283 million m^3 (10 BCF)] has been obtained from these rocks. In Ohio's northern counties, these rocks have produced about 1 billion m^3 (37 BCF) on shore, including 710 million m^3 (25 BCF) from Cuyahoga County (Cleveland). There is no history of significant gas production from Lockport rocks in the vicinity of Lake Erie in New York.

To date, it is unknown whether the Lockport reef trends observed in Ontario extend into USLE. If they do, they will most likely be found north and west of Lake County, Ohio.

The Lockport dolomite is assigned *possible* reserves of 1.4-8.5 billion m^3 (50-300 BCF). Some oil may be present in the Lockport on the far west side of USLE (north and east of Marblehead Peninsula, Ohio).

Devonian System

The only Devonian formation under USLE that is considered a possible commercial reservoir is the Oriskany sandstone. The Oriskany has produced about 311 million m^3 (11 BCF) in Ohio in the vicinity of Lake Erie and has been productive in a few areas in Erie County, Pennsylvania. The formation present beneath USLE extends from Cleveland, Ohio, to eastern Erie County, Pennsylvania; it extends for unknown, but probably small and irregular, distances away from the shore. The formation may produce from both stratigraphic and structural traps. The former, existing onshore, are productive in only a few places; the latter are not known to exist under USLE. The Oriskany is assigned *possible* reserves of 710 million m^3 (25 BCF).

The upper Devonian shale, bedrock along much of the shore of USLE and in much of USLE (below unconsolidated sediments), has produced small and essentially domestic quantities of gas in Ohio, Pennsylvania, and New York. Wells drilled into the shale are generally less than 305 m (1000 ft) deep. In the vicinity of Fredonia, New York, gas escaped from the shale at or near the surface and was used to fuel streetlights. Although the shale is not considered a commercial gas reservoir, it is possible that very small quantities of gas may be escaping from it under USLE. High-pressure shale gas present near the top of bedrock under USLE would have been released at the time the lake basin was gouged out by glacial action about 10,000 years ago; subsequent gas seepage would and will be of very low magnitude since shale has virtually no permeability except that created by post-depositional fracturing.

In the past ten years perhaps a dozen (out of more than 1500) wells drilled to the lower Silurian sandstones in northeastern Ohio penetrated high-pressure shale gas at depths of 61-152 m (200-500 ft) in the upper Devonian shale. However, the shale thins very rapidly away from the land area, and the section containing the high-pressure gas will likely be absent under USLE.

Comparison of Project Staff Estimates with Previously Published Estimates

Previously published estimates of gas reserves under USLE have been made for the entire area by Bulmer and Bulmer (1972), for the Ohio portion by Clifford (1975), and for the New York portion by Van Tyne (1976).

Bulmer and Bulmer. Pertinent data from Bulmer and Bulmer (1972) are shown in Table 13. Their study area differs from that used in this report because they included Ohio's total area, including that called the western basin of Lake Erie which was excluded from this report. Nor did they exclude the areas of two buffer zones for Ohio, Pennsylvania, and New York excluded in this report.

The principal reason for differences in gas reserve estimates between Bulmer and Bulmer's and those of this report is: production estimates from the Ordovician are not considered in this report because the potentially productive area lies in the western basin.

Bulmer and Bulmer's anticipated natural gas reserves per well [= per 2.6 km^2 (640 acres)] in the lower Silurian sandstones are 33 million m^3 (1.2 BCF) as compared with 17 million m^3 (0.6 BCF) cited in this report.

Table 13. Reserves (BCF) Estimated by Bulmer and Bulmer (1972)[a]

	Cambrian	Ordovician	Lower Silurian	Lockport	Oriskany
New York	12.5	0	438.4	0	0
Ohio	57.4	23.1	1,444.2	380	0
Pennsylvania	16.1	0	563.9	0	0
Totals	86.0	23.1	2,446.5	380	0
This report	25-100[b]	0	1,231[c]	50-300[b]	25[b]

[a]Oil reserves estimated for Cambrian and Ordovician rocks are not included. BCF = billions of cubic feet. To convert cubic feet to cubic meters, multiply by 0.02832.

[b]*Possible* reserves.

[c]*Probable* reserves (New York, 193; Ohio, 772; Pennsylvania, 266).

Beyond the statement that what is being discussed are *estimates* of unknown recoverable reserves, the figure in this report appears reasonable, considering and extrapolating from the known productivity of the lower Silurian sandstones along the south shore of Lake Erie.

Clifford. Clifford (1975) estimated the reserves underlying the Ohio portion of Lake Erie. His estimates included oil reserves in Cambrian and Ordovician rocks; most of these reserves underlie the western basin. He estimated that the lower Silurian sandstones contain reserves of 19 billion m^3 (670 BCF); the corresponding estimate from data and assumptions used in this report is 22 billion m^3 (772 BCF). The two relatively minor differences between the two sets of data and assumptions are: (1) Clifford assigned reserves of 14 million m^3 (0.5 BCF) to each well [per 2.55 km^2 (630 acres)]; in this report 17 million m^3 (0.6 BCF) are assigned to each 2.6 km^2 (640 acres), and (2) Clifford's net productive area was 526,000 ha (1,300,000 acres); in this report that figure is reduced by 13,355 ha (33,000 acres) because of the likelihood of oil production off Ashtabula County.

Clifford assigned possible reserves of 11-21 billion m^3 (375-750 BCF) to the Lockport formation ("Newburg"); in this report, these figures are 1.4-8.5 billion m^3 (50-300 BCF). The principal difference between the two estimates is the area considered. Clifford hypothesized that one or two Tilbury-type barrier reefs may be present in Ohio's portion of Lake Erie, including the western basin; in this report, it is considered probable that one of these fields may be found in the Ohio portion of Lake Erie, excluding the western basin.

The Oriskany formation was not assigned reserves by Clifford. In this report, 0.7 billion m^3 (25 BCF) are assigned for this formation.

Van Tyne. Van Tyne (1976) gave estimates of the gas reserves underlying the New York portion of Lake Erie. He gave the area as 151,075 ha (373,315 acres) and made the following approximate reserve assignments:

Lockport	1.4 billion m^3 (50 BCF)
lower Silurian sandstones	5.7 billion m^3 (200 BCF)
Cambrian and Ordovician	1.4 billion m^3 (50 BCF)

In this report, the corresponding figure for New York reserves in the lower Silurian sandstones is 5.5 billion m^3 (193 BCF). It is not considered likely that the Lockport will produce gas in the New York portion of Lake Erie, and it is considered probable that more than 80 percent of the possible reserves assigned to the Cambrian will be present in the Ohio portion of USLE. No reserves are assigned to Ordovican rocks below USLE.

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ECONOMIC OVERVIEW

CHARACTERIZATION OF THE NEED FOR NATURAL GAS

National Production, Consumption, and Curtailments

Natural gas production in the United States peaked in 1973 at 640 billion m^3 [22.6 trillion cubic feet (TCF)] (Table 14). Proved recoverable reserves of natural gas reached a high in 1967 with an estimated 8.27 trillion m^3 (292 TCF). With the exceptions of 1970, when Alaskan reserves were added to the inventory, and of 1971, gas reserves have declined every year since 1967. Gas reserve additions have amounted to less than annual production since 1968 (except for 1970).

A combination of events, including severe winters and a trend toward national economic recovery, stimulated demand for natural gas during the mid-1970s. At the same time, annual additions of gas reserves fell short of annual marketed production. The interaction of mildly stimulated demand and steadily decreasing domestic supplies resulted in shortages of natural gas for some interstate pipeline companies. The growing shortage of natural gas, particularly during the heating season (November-March), resulted in a system of imposed curtailments regulated by the Federal Energy Regulatory Commission (FERC). In 1970, curtailments imposed on interstate pipelines amounted to less than one percent of requirements. In 1974, these curtailments increased to 10 percent. Data for the 1976-1977 heating season reveal that U.S. consumers were curtailed by 25.8 percent of total gas requirements (U.S. Dep. Energy 1977).

Although all areas of the United States experienced gas shortages in the past few years, there were significant regional disparities. The upper Midwest, an area of harsh winters, experienced about 12 percent curtailment in gas deliveries during the 1976-1977 heating season. During the same period, southeastern states had a 42 percent curtailment in gas requirements (U.S. Dep. Energy 1977).

In addition to regional shortages of natural gas, curtailments were imposed on specific economic sectors. Natural gas supplies about 47 percent of industry's energy needs. During the 1976-1977 heating season, the industrial sector was curtailed by 28 percent of gas requirements resulting in widespread unemployment and economic hardships, particularly in the heavily industrialized states (U.S. Dep. Energy 1977).

Production, Consumption, and Curtailments in the Tri-State Region

Although New York, Pennsylvania, and Ohio are gas-producing states, demand for gas in each is much greater than total production. Total gas production for the three states in 1975 was 5.05 billion m^3 [178.2 billion ft^3 (BCF)] (Table 15). Ohio was the major producing state with a gross production of 2.43 billion m^3 (85.8 BCF) of gas (Am. Gas Assoc. 1976).

Table 14. Natural Gas in the United States, 1967-1976[a]

	Natural Gas (TCF)[b]		
Year	Annual Gross Additions to Proved Reserves	Proved Reserves	Marketed Production[c]
1967	21.8	292.9	18.2
1968	13.7	287.4	19.3
1969	8.4	275.1	20.7
1970	37.2	290.8	21.9
1971	9.8	278.8	22.5
1972	9.6	266.8	22.5
1973	6.8	249.9	22.6
1974	8.7	237.1	21.6
1975	10.5	228.2	20.1
1976	7.6	216.0	19.9

[a]Data from American Gas Association (1977).

[b]TCF = trillions of cubic feet. To convert cubic feet to cubic meters, multiply by 0.02832.

[c]Marketed production equals total gross production less "repressuring and vented and flared" gas.

Table 15. Estimated Gross Production and Deliveries to Consumers of Natural Gas, 1955-1975[a]

	Natural Gas (BCF)[b]			
Year	New York	Ohio	Pennsylvania	Total
		Estimated Gross Production		
1955	4.0	35.0	99.8	138.8
1970	3.4	52.1	77.1	132.6
1975	7.6	85.8	84.8	178.2
		Delivered to Consumers		
1955	242.1	494.6	378.9	1,115.6
1970	707.2	1,037.8	743.4	2,488.4
1975	574.0	944.9	634.3	2,153.2

[a]Data from American Gas Association (1976).

[b]BCF = billions of cubic feet. To convert cubic feet to cubic meters, multiply by 0.02832.

Total demands for natural gas have continued to exceed supply, and curtailments have been commonplace. Ohio's gas requirements during the 1976-1977 heating season were 19.59 billion m^3 (691.7 BCF) whereas deliveries totaled 16.4 billion m^3 (579.1 BCF), resulting in a 16.3 percent usage curtailment (Table 16). New York and Pennsylvania experienced gas curtailments of 9.5 and 11.9 percent, respectively, during the same time period (U.S. Dep. Energy 1977).

Curtailments of required supplies to industry in the tri-state region, however, present a different picture. Gas curtailments to the industrial sector in Ohio reached 47 percent of requirements during the 1976-1977 heating season, forcing many industries to shut down. Ohio ranked fourth in the nation in terms of the volume of gas curtailed to industry (U.S. Dep. Energy 1977). New York and Pennsylvania fared only slightly better with a 28.2 and 34.7 percent reduction in gas requirements to industry (U.S. Dep. Energy 1977).

Lake Erie Study Area

The study area encompasses the northern counties of the three states bordering Lake Erie: New York (Erie and Chautauqua counties), Pennsylvania (Erie County), and Ohio (Ashtabula, Lake, Cuyahoga, Lorain, Erie, Sandusky, and Ottawa counties). The area is heavily urbanized and is characterized by an industrial profile of durable goods--iron and steel production, fabricated metal products and machinery, transportation equipment, and petrochemical industries.

County Consumption Patterns

Projections of gas consumption data for the tri-state study area were obtained from the Natural Gas/Fuel FORECAST (NG/FF) (McGraw-Hill, Inc. 1978).* Data were given for gas consumption by state, by county, and by industry for large end-users for a twelve-month period ending 31 March 1978 (NG/FF data collection period). Large end-users are defined as consumers whose combined deliveries and curtailments equal 2.8 million m^3 [100 million cubic feet (MMCF)] per year.

Within the ten-county region, Ohio consumed more natural gas than Pennsylvania and New York combined (Table 17). This was the result of the extent of Ohio's Lake Erie shoreline and the industrial dominance of the Cleveland area (Cuyahoga County). Cuyahoga County consumed 48 percent of the total gas deliveries to the study area. Industries in the Ohio counties consumed 74 percent of the total 2.85 billion m^3 (100.5 BCF) of gas consumed by all large end-users in the region.

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*These *projections*, based on the most current information available at the time this report was being prepared (McGraw-Hill, Inc. 1978), have been treated as actual data in the text for the purpose of readability. The actual data for the 1977-1978 NG/FF data collection period will be published by McGraw-Hill, Inc., later this year.

Table 16. Natural Gas Deliveries and Curtailments during the 1975-1976 and 1976-1977 Heating Seasons

State	Natural Gas (BCF)[a]		
	Deliveries	Curtailments	Curtailments as % of Requirements
		1975-1976[b]	
New York	363.6	29.6	7.5
Ohio	525.0	73.9	12.4
Pennsylvania	375.7	27.9	6.9
		1976-1977[c]	
New York	387.9	40.8	9.5
Ohio	579.1	112.0	16.3
Pennsylvania	407.1	55.2	11.9

[a]BCF = billions of cubic feet. To convert cubic feet to cubic meters, multiply by 0.02832.

[b]Data from Federal Power Commission (1977).

[c]Data from U.S. Department of Energy (1977).

Table 17. Projected Natural Gas Consumption and Curtailments by County and Major Industrial Group for the Ten-County Study Area, April 1977-March 1978[a]

County	Natural Gas (MCF)[b]		SIC[c]	Major Industrial Group	Natural Gas (MCF)[b]	
	Deliveries	Curtailments			Deliveries	Curtailments
New York						
Erie	18,170,628	0	33	Primary metal	10,841,554	0
Chautauqua	2,918,247	0	33	Primary metal	1,250,100	0
Total	21,088,875	0			12,091,654	0
Ohio						
Cuyahoga	48,585,836	1,002,806	33	Primary metal	33,429,598	617,482
Lorain	9,462,107	2,106,077	33	Primary metal	6,690,350	618,974
Lake	4,241,904	174,203	28	Chemicals, allied products	2,889,246	55,493
Ashtabula	4,229,718	139,279	28	Chemicals, allied products	1,915,685	95,984
Sandusky	3,334,721	1,542,328	32	Stone, clay, glass, concrete	1,702,340	138,396
Erie	2,946,883	1,007,879	32	Stone, clay, glass, concrete	1,120,202	144,710
Ottawa	2,023,130	425,193	32	Stone, clay, glass, concrete	1,443,695	74,306
Total	74,824,299	6,397,765			49,191,116	1,745,845
Pennsylvania						
Erie	4,585,582	40,044	33	Primary metal	2,907,776	0
Total	4,585,582	40,044			2,907,776	0
Total				Total		
10-County Study Area	100,498,256	6,437,809		Major Industrial Groups	64,190,546	1,745,845

[a]Data from McGraw-Hill, Inc. (1978).

[b]MCF = thousands of cubic feet. To convert cubic feet to cubic meters, multiply by 0.02832.

[c]SIC = Standard Industrial Classification.

Gas Intensive Industries

Three groups of industries, primary metal [Standard Industrial Classification 33 (SIC 33)]; stone, clay, glass, and concrete (SIC 32); and chemicals and allied products (SIC 28) constitute the major gas-consuming industries in the tri-state region. These industries utilized over 73 percent of all gas consumed by major end-users in the ten-county area (Table 18).

Table 18. Projected Total Natural Gas Deliveries and Curtailments to Major Industrial Groups for the Ten-County Study Area, April 1977-March 1978[a]

		Natural Gas (MCF)[b]	
SIC[c]	Major Industrial Group	Deliveries	Curtailments
33	Primary metal	56,429,065	1,484,193
32	Stone, clay, glass, concrete	9,585,232	583,003
28	Chemicals, allied products	7,731,597	1,013,144
37	Transportation equipment	6,853,219	166,778
34	Fabricated metal products, except machinery	4,664,996	468,251
36	Electrical, electronic machinery	2,451,157	462,537
20	Food and kindred products	2,430,796	933,799
35	Machinery, except electrical	2,159,126	103,672
30	Rubber, miscellaneous plastics products	2,138,680	344,605
29	Petroleum refining, related industries	1,252,851	410,828
39	Miscellaneous manufacturing industries	1,015,753	106,583
26	Paper, allied products	955,594	20,808
80	Hospitals	485,368	0
82	Schools	413,678	11,842
40	Railroad transportation	347,262	6,730
49	Electric utilities	323,639	56,107
22	Textile mill products	254,906	119,423
25	Furniture, fixtures	198,241	3,547
27	Printing, publishing	170,038	0
52	Building materials, hardware stores	110,236	0
96	Economic programs	109,248	68,256
1	Agricultural, crops	100,567	24,725
65	Real estate	98,698	1,593
70	Hotels, lodging places	94,533	0
50	Wholesale trade—durables	84,276	47,385
	Total	100,498,756	6,437,809

[a]Data from McGraw-Hill, Inc. (1978).

[b]MCF = thousands of cubic feet. To convert cubic feet to cubic meters, multiply by 0.02832.

[c]SIC = Standard Industrial Classification.

Primary metal production is the most important gas-consuming industry in the study area. The industry consumed more than 1.6 billion m^3 (56.4 BCF) of gas during the NG/FF data collection period, or over 50 percent of all the natural gas consumed by large end-users. Iron and steel producers are the most important gas-consuming industries in five of the ten counties in the study area (Chautauqua and Erie counties, New York; Erie County, Pennsylvania; Cuyahoga and Lorain counties, Ohio) and are second in importance in two other counties. A listing of the ten largest gas-consuming companies in the region includes nine primary metal producers. The largest, Jones & Laughlin (Cuyahoga County, Ohio), consumed 371 million m^3 (13.1 BCF) of gas during the twelve-month study period (Table 19).

Table 19. Projected Largest End-Users of Natural Gas in the Study Area, 1977-1978[a]

Company	Deliveries (MCF)[b]	SIC[c]	County
Jones & Laughlin Steel Corp.	13,118,316	33	Cuyahoga, Ohio
Bethlehem Steel Corp.	7,874,000	33	Erie, New York
Republic Steel Corp.	6,390,000	33	Cuyahoga, Ohio
U.S. Steel Corp.	6,317,452	33	Lorain, Ohio
U.S. Steel Corp	2,115,977	33	Cuyahoga, Ohio
National Forge	2,100,000	33	Erie, Pa.
Aluminum Company of America	2,051,006	33	Cuyahoga, Ohio
Ford Motor Co.	1,880,147	33	Cuyahoga, Ohio
Chevrolet River Road Plant	8,829,449	37	Erie, New York
Republic Steel Corp.	1,752,593	33	Erie, New York
Huron Lime	1,120,202	32	Erie, Ohio
Union Carbide Corp.	1,063,477	32	Ashtabula, Ohio

[a]Data from McGraw-Hill, Inc. (1978). A large end-user is defined as using > 1 billion cubic feet (BCF) of gas during a 12-month period. One BCF = 28.32 million cubic meters.

[b]MCF = thousands of cubic feet. To convert cubic feet to cubic meters, multiply by 0.02832.

[c]SIC = Standard Industrial Classification.

Stone, clay, glass, and concrete producers constitute the second most important group of gas-consuming industries in the region utilizing about 269 million m^3 (9.5 BCF) of gas. Geographically, this industry is highly concentrated in Ohio, particularly in the western part of the study area. It is the major gas-consuming industry in Erie, Sandusky, and Ottawa counties.

Chemicals and allied products comprise the third largest group of gas-consuming industries, utilizing approximately 218 million m^3 (7.7 BCF) of gas. Although the industry is located in several counties of the study area, it is highly concentrated in northeastern Ohio (Ashtabula and Lake counties) where it is the most important gas-consuming industry. The chemicals and allied products industry experienced some of the largest gas curtailments (both in volume and as a percentage of total requirements) during the twelve-month NG/FF data collection period.

Natural Gas Curtailments in the Lake Erie Study Area

A pattern of gas curtailments by county can be noted within the tri-state region. During the NG/FF data collection period, large end-users of natural gas in northern Ohio were significantly curtailed, whereas consumers in Pennsylvania and New York experienced almost no disruption in service. Supplies reaching end-users may be reduced if quantities of natural gas transported by pipeline companies are curtailed. Northeast Ohio (Ashtabula, Cuyahoga, and Lake counties) is serviced by East Ohio Gas; northwest Ohio (Erie, Lorain, Ottawa, and Sandusky counties) is serviced by Columbia Gas of Ohio. Both pipeline companies imposed severe curtailments upon end-use customers. In contrast, the study area in New York and Pennsylvania is primarily serviced by National Fuel Gas Distribution Corporation which did not significantly curtail its customers in 1977-1978. Natural gas curtailments in the study area totaled 181 million m^3 (6.4 BCF) during the NG/FF data collection period. But, over 99 percent of the gas curtailments were to large end-users in Ohio.

Potential Lake Erie Gas Production

Using assumptions that describe the timing of potential Lake Erie gas exploitation, a scenario was created to present a possible range of USLE annual production rates (see Appendix A). The scenario assumes two possible annual production rates for gas wells [510,000 and 850,000 m^3 (18 and 30 MMCF) per well per year]. Total estimated natural gas production over a 22-year period is anticipated to fall within the range of 15-25 billion m^3 (533-888 BCF). At present rates of consumption, estimated U.S. Lake Erie resources could supply from five to nine years of natural gas to the ten-county study region. The scenario demonstrates that after four years of operation [@ 850,000 m^3 (30 MMCF) per well per year] and five years of operation [@ 500,000 m^3 (18 MMCF) per well per year] total annual production potential from USLE [289 million m^3 (10.2 BCF) per year and 246 million m^3 (8.7 BCF) per year, respectively] would exceed industrial curtailments projected for the 1977-1978 NG/FF data collection period [181 million m^3 (6.4 BCF) per year]. Assuming that this increased supply capacity could actually be delivered to curtailed industrial users, the economic benefits resulting from maintenance of full industrial potential in the ten-county study area could be significant. Furthermore, the scenario also predicts that annual Lake Erie production would increase up to 1.9 billion m^3 (68 BCF) per year [@ 850,000 m^3 (30 MMCF) per well per year] and 1.2 billion m^3 (41 BCF) per year [@ 510,000 m^3 (18 MMCF) per well per

year] after 22 years of operation. Development of Lake Erie gas could be a valuable resource for those industries that utilize natural gas as an essential part of the production process (primary metals) or as a feedstock (chemicals and allied products).

POTENTIAL NATURAL GAS PRODUCTION FROM U.S. LAKE ERIE RESOURCES

Expected Production According to Scenario Development

The scenario, developed to demonstrate the effects of natural gas production in USLE, is described in detail in Appendix A; it provides for a maximum production of gas over a period of 22 years, ending in year 2000. It does not reflect economic or institutional constraints that might be expected in the development and production of Lake Erie gas. Except for production rates from each well, the scenario is based entirely on data from the Canadian Lake Erie gas development program. Actual Canadian production per well has not recently (within the last five years) matched previous estimates for that production.

Figure 7 illustrates two possible depletion rates for wells and shows a range of potential production capacities. The lower value for annual average production, 510,000 m^3 (18 MMCF), is based on estimates made by the New York State Energy Office (1977). The higher value, 850,000 m^3(30 MMCF), is from Canadian estimates by the Ontario Ministry of Natural Resources (Hurd and Kingston 1978). In 1977, the Canadian portion of Lake Erie produced 153 million m^3 (5.4 BCF) from 300 wells, an average of 510,000 m^3 (18 MMCF) per well per year.

The scenario chosen describes circumstances that produce 15.1 billion m^3 (533 BCF) of natural gas for the 510,000 m^3 (18 MMCF) per well per year figure and 25.1 billion m^3 (888 BCF) for 850,000 m^3 (30 MMCF) per well per year during the total life of the project (22 years). The Canadian drilling program had resulted in the production of 3.2 billion m^3 (114 BCF) of gas by the end of 1977 (Hurd and Kingston 1978). Over 1000 wells have been drilled on the Canadian side of the Lake since 1913; 300 were active in 1977, and another 130 could have produced but were awaiting connection to an underwater collection system. Of the total wells drilled, 95 percent have been drilled since 1955 and more than 50 percent since 1969.

Known Canadian Lake Erie gas reserves have been estimated to be 5.1 billion m^3 (180 BCF) (Hurd and Kingston 1978); the location of these resources is known and they can be exploited at current costs (and prices) plus inflation and with current technology. Potential Canadian resources are estimated to be 28.3 billion m^3 (1000 BCF) (Hurd and Kingston 1978); the location of these is not known and they would incur higher costs (and prices) and might require technological improvement for full exploitation.

Assuming similar geologic conditions and equivalent lakebed surface areas in Canadian and U.S. portions of Lake Erie, potential resources in USLE are estimated to be the same as the Canadian, 28.3 billion m^3 (1000 BCF) (Hurd and Kingston 1978), for the purpose of economic analysis. Canadian development has already exploited 10 percent of its potential resources. Estimates indicate that another 20 percent is extractable with current knowledge and at

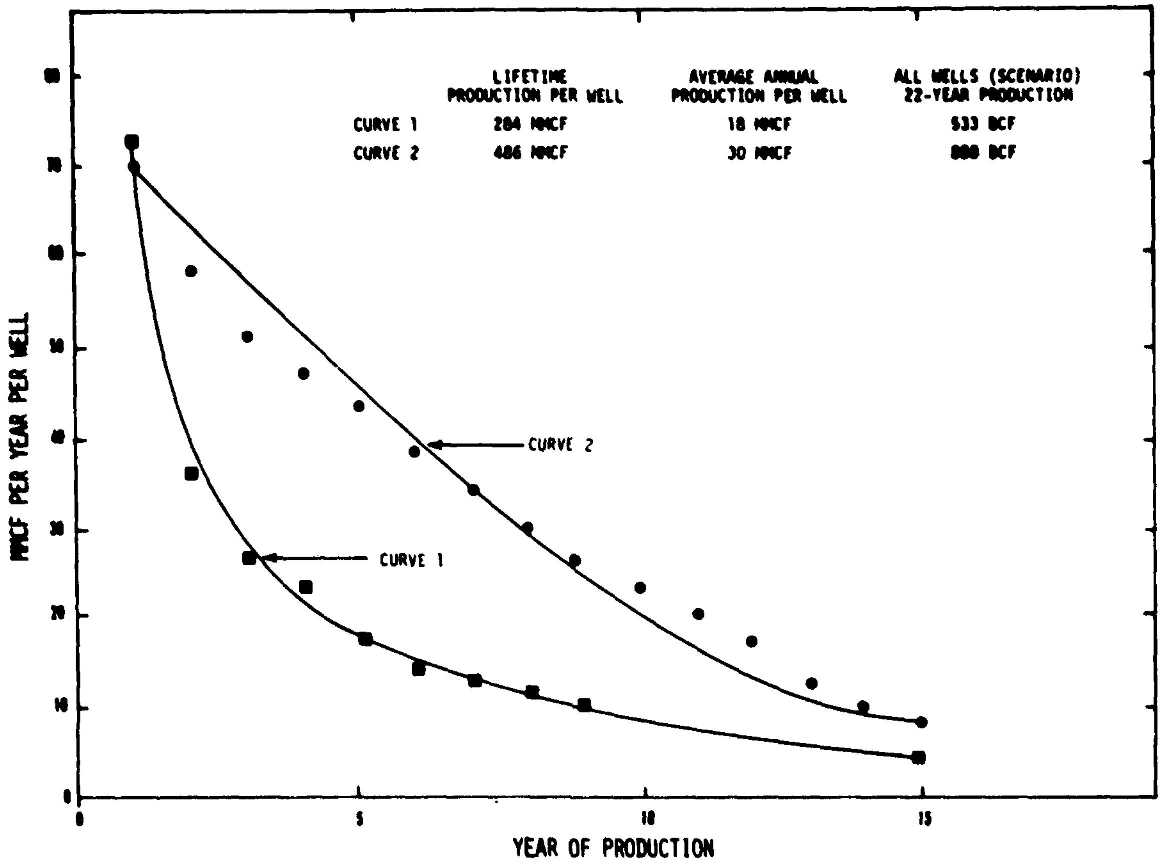

Figure 7. Estimated Production Decline for Lake Erie Gas Wells. Data from New York State Energy Office (1977) and Hurd and Kingston (1978).

current costs. The scenario assumes that 50-90 percent of the potential resources for the United States could be exploited with present knowledge. Table A.1 (Appendix A) shows the area of lakebed that could be used for Lake Erie gas production by New York, Pennsylvania, and Ohio.

Figure 8 presents a map showing the relative areas of the Lake available to the United States and Canada and those areas of the Canadian side which are considered producers. Figure 9 roughly shows the Canadian underwater natural gas collection system for Lake Erie production. There are an estimated 13 points of entry to onshore pipelines for the existing Canadian production network.

Major Equipment and Employment Estimates

Manpower estimates were made for the following operations: drilling, well stimulation (fracturing), well maintenance, third-party assistance (independent contractors) to drilling and maintenance, construction and laying of the

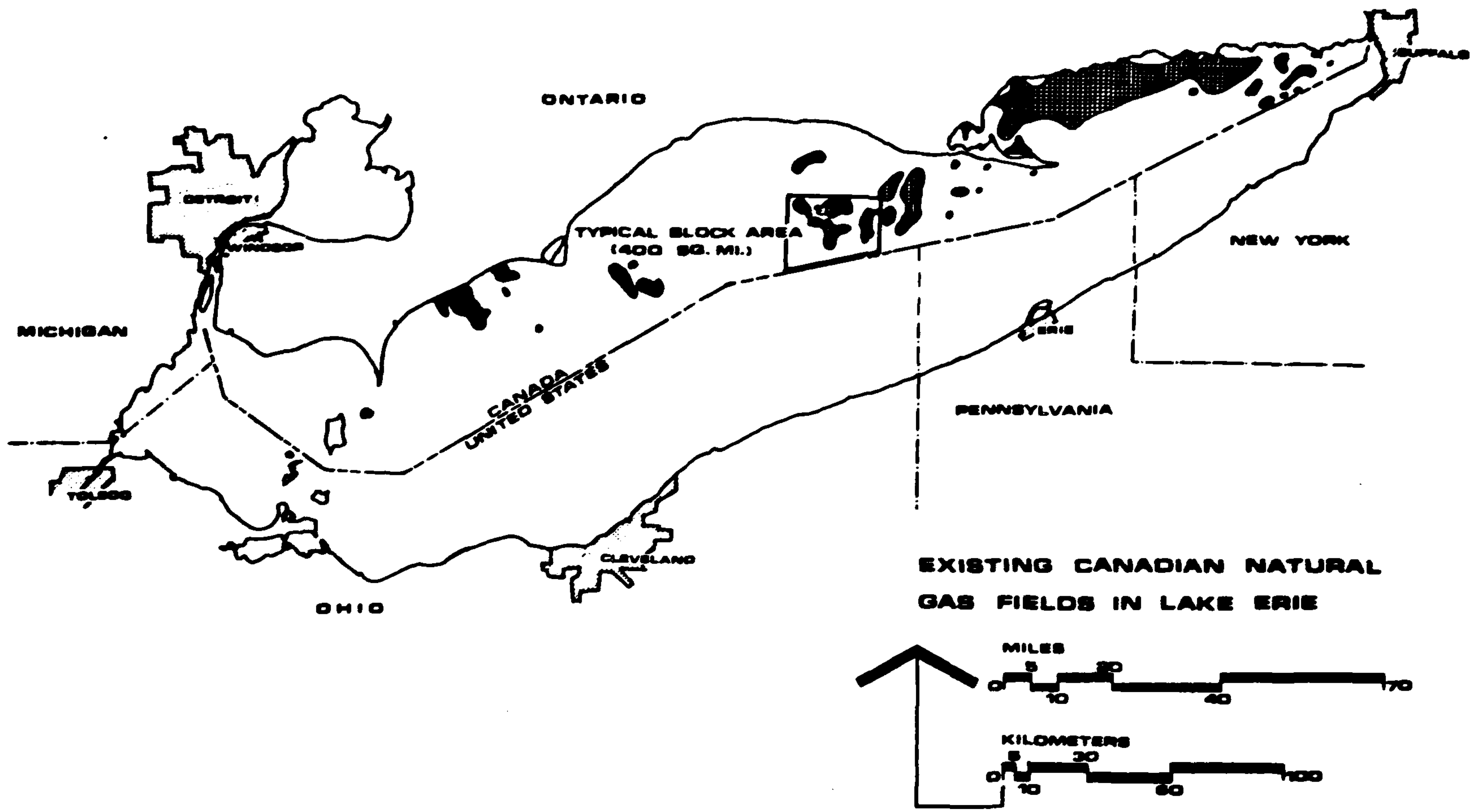

Figure 8. Existing Canadian Natural Gas Fields in Lake Erie. Data from Hurd and Kingston (1978).

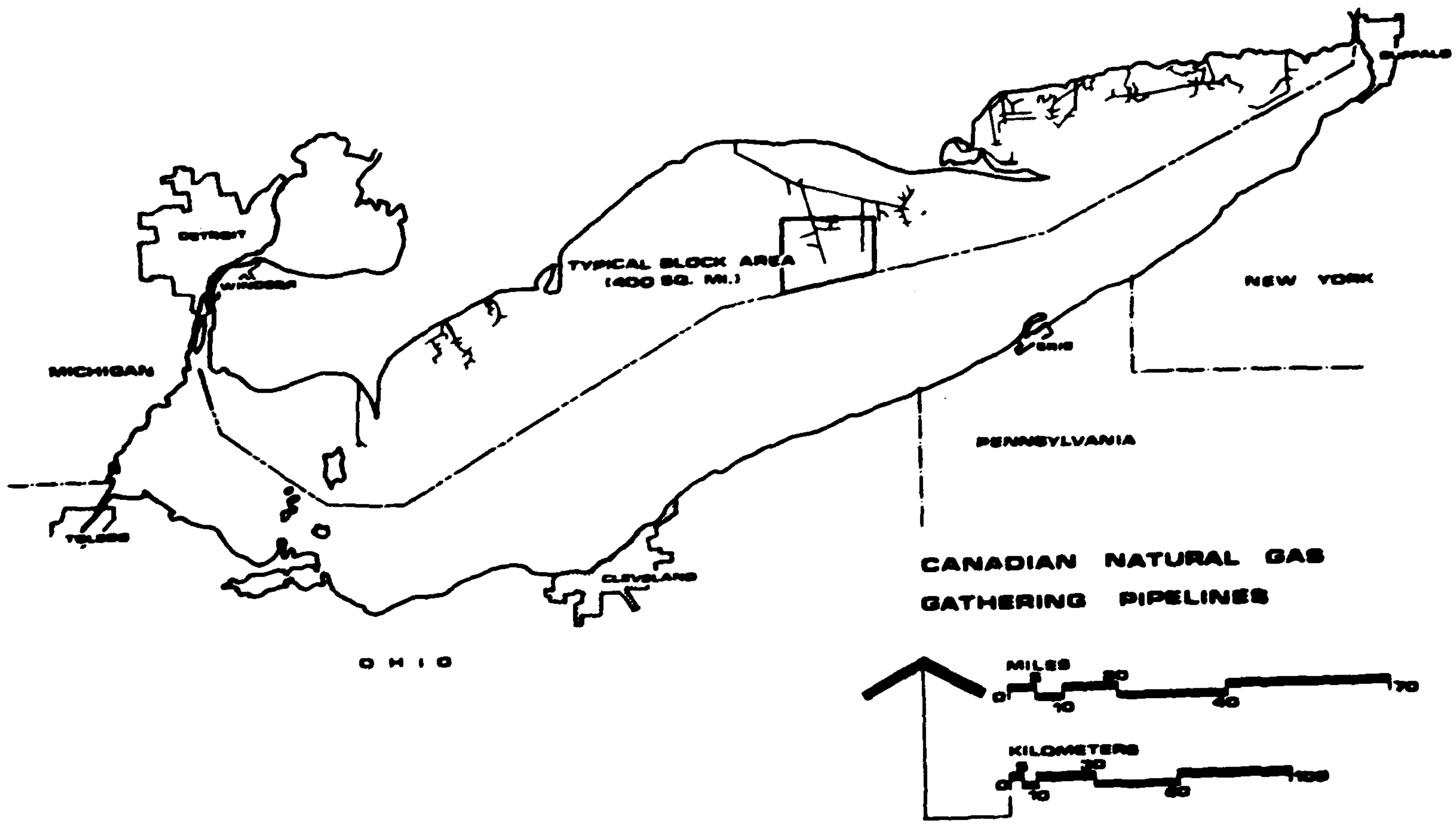

Figure 9. Underwater Gas Collection System for Canadian Lake Erie Natural Gas Production. Data from Hurd and Kingston (1978).

underwater collection system, and construction of landfalls and land facilities. Estimates of the potential number of people involved in the exploration, development, and production of U.S. Lake Erie gas are given in Table A.3 (Appendix A).

Nine drilling rigs are assumed to be used throughout the first 15 years of the 22-year production period. A tenth rig is added in the sixteenth year to make up for the lost production from early wells which are depleted in that sixteenth and subsequent years. Thirty-man crews made up of three groups of ten workers are assumed for each rig. Of these three groups, two would be on board and working alternately, the third would be onshore.

Four well stimulation barges are assumed to operate throughout the 22-year project life. The barges would travel widely over the U.S. waters of the Lake. Each barge would serve about 40 wells each year. A six-month drilling season would require fracturing of about 2 wells every 10 days. Since fracturing would take only about a day, 2 to 4 days of travel and set-up time per week would be allowed.

Maintenance and third-party employment was estimated to be 300 people at maximum production. These people would compose the labor force needed for pipe laying, repairs, and underwater pipeline inspection. The underwater collection system would be welded onshore, floated from shore to its Lake position, then sunk in place. In addition to third-party employment related to drilling services, approximately 400 people would be employed annually after the fifteenth year of project operation for collection system construction. Canadian experience indicates a need for one landfall for every 40-60 wells and this was the basis for that portion of the above estimates (Hurd and Kingston 1978).

Canadian experience (expressed as dollar costs for the collection system, maintenance, and third-party functions) was converted to annual payroll costs to derive the numbers of people involved in gas production.

As would be expected in projects where parts of the production system must be functional before others can start (e.g., wells must be drilled, fractured, and determined to be producers before gathering pipelines are laid), employment is low at the start and gradually increases to a maximum. For the scenario, maximum employment is reached after 15 years of production; at that time employment levels reach 1,040 people. No effort was made to determine the grade levels of the people employed. The skill levels required for all operations will probably be high. Because an adequate number of people having the required skills are presumed to live along the northern Lake Erie shore, there should be no major labor market dislocations.

Estimated Cost of Lake Erie Gas: Difference between Cost and Price

A cost estimate of U.S. Lake Erie gas was based on the actual costs reported by the Ontario (Canada) Ministry of Natural Resources (Hurd and Kingston 1978). Two figures for well production were chosen; these are also based on Canadian estimates and actual production figures (see Fig. 7). The year-by-year costs and natural gas production data were developed as shown in Table A.4 (Appendix A) based on the assumptions described in Appendix A.

Total costs for the 22-year life of the project are estimated to be \$1.077 billion (1978 U.S. dollars). Unit prices (see paragraph below) are obtained by dividing this total cost by total production for either of the two chosen production rates.

Average unit costs in U.S. dollars per thousand cubic feet (MCF)* are \$2.02 for the low annual production [510,000 m^3 (18 MMCF) per well per year or 1400 m^3 (50 MCF) per day] and \$1.21 for the high annual production rate [850,000 m^3 (30 MMCF) per well per year or 2300 m^3 (82 MCF) per day]. These cost estimates do not include profit or federal taxes. They cannot be compared directly to quoted prices, since the latter would include federal taxes and profits.

The cost estimates (\$1.21 and \$2.02 per MCF) are, however, comparable to current quoted prices at the wellhead; i.e., they are a reflection of the gas cost or price at the first point of transfer beyond the well itself (from wellhead to underwater collection system). Two subsequent transfers occur in the usual sequence followed in bringing the gas to the ultimate consumer. The second transfer is from the collection system to either an intrastate or interstate pipeline. In most gas sales, the third transfer is from the pipeline to a distribution system that delivers the gas to the ultimate consumer. Some very large users (e.g., primary metal producers) receive their gas directly from the pipeline. Both pipeline and distribution companies are considered to be public utilities as differentiated from production companies that produce the gas from the drilled wells.

Consequently, three increments of cost and price determination can occur during the production and delivery of U.S. natural gas. These are wellhead, pipeline, and distribution increments. Each increment has a cost and a price, the latter including profit and federal and state taxes. Costs are made up of operating and maintenance charges plus the depreciation and royalties paid. In the gas industry, the depreciation and royalty components of costs are usually greater than the fraction required for operation and maintenance.

In order to compare the estimates of cost for Lake Erie gas with available prices, it was necessary to estimate a price by making an estimate for return on investment and taxes. In order to have a return of 12.5 percent (chosen for illustrative purposes) with a tax rate of 50 percent, the cost of production was multiplied by 1.25.

Comparison of Potential Lake Erie Resources with Alternative Gas Supplies

For the purpose of economic analysis, gas resources in Lake Erie waters of each state were estimated by dividing a conservative estimate of USLE resources [28.3 billion m^3 (1000 BCF)] into fractions proportional to the land area under drillable portions of each state's waters (see Table A.1, Appendix A). Therefore, since New York has 14.6 percent of the USLE surface area, it was assigned gas resources of 4.1 billion m^3 (146 BCF). Ohio and Pennsylvania occupy 66.6 and 18.8 percent of the USLE surface area; consequently, they were assigned offshore resources of 18.9 billion m^3 (666 BCF) and 5.3 billion m^3 (188 BCF), respectively.

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*To convert cubic feet to cubic meters, multiply by 0.02832.

Onshore demonstrated (measured and indicated) reserves have been reported by Samsa, et al. (1977). These reserve estimates are presented in Table 20. The development of Lake Erie natural gas would significantly increase demonstrated onshore reserves in New York, Ohio, and Pennsylvania by 67.6, 49.2, and 11.2 percent, respectively.

Table 20. Onshore Demonstrated Reserves and Offshore Lake Erie Resources for New York, Ohio, and Pennsylvania[a]

State	Demonstrated[b] Onshore Reserves (BCF)[c]	Offshore Resources (BCF)[c]	Percentage Increase in Reserve Base from Addition of Offshore Resources
New York	216	146	67.6
Ohio	1,354	666	49.2
Pennsylvania	1,682	188	11.2

[a]Data from Samsa et al. (1977). [Data originally from American Gas Association (1975).]

[b]Demonstrated reserves are the sum of measured and indicated reserves. These estimates represent reserves as of 31 December 1975.

[c]BCF = billions of cubic feet. To convert cubic feet to cublic meters, multiply by 0.02832.

The potential onshore resources for a 13-state region* surrounding or near the Great Lakes is 2.7 trillion m^3 (94 TCF) (Stanford Res. Inst. 1977). U.S. Lake Erie offshore resources [28.3 billion m^3 (1 TCF)] represent about one percent of this reserve base.

The use of current prices for natural gas produced in Ohio, New York, and Pennsylvania as a basis for determining the potential for Lake Erie gas development could be misleading. In each of the three states, gas prices for within-state production have escalated immensely over the last six years [376% in Ohio, 245% in Pennsylvania, and 372% in New York (DeBrosse 1978; U.S. Dep. Energy 1978b)]. In Ohio, the wellhead price increased 38 percent between 1976 and 1977 to a value of $1.40 per MCF. Such rates of increase, if continued, would increase the economic potential for Lake Erie gas development.

*Minnesota, Iowa, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania, New York, West Virginia, Virginia, Kentucky, and Tennessee.

Lake Erie gas could be considered to be competitive with currently available substitutes such as imported liquid natural gas (LNG), propane, and butane, and probably with gas from Alaska and even with imports from Canada and Mexico. Synthetic gas (SNG) from coal is not now available but will probably be priced even higher than imported liquid gas. None of these gases are currently under price regulation by federal agencies.

If federal regulation of interstate natural gas continues, it is improbable that gas from Lake Erie could compete with the substitutes listed above, and this would mandate intrastate use. Since Ohio produced only 10 percent of its total requirements for gas in 1977, any substantial increase in state production capacity would tend to stabilize supply and reduce curtailment potential.

Lake Erie gas could provide important additions to the reserves within each of the states bordering the Lake. If used within the state, Lake Erie gas would be competitive with intrastate production, particularly if prices for intrastate gas continue to rise. In general, prices for Lake Erie gas would compare favorably with prices for synthetic gases made from petroleum liquids or coal.

Comparison of Anticipated Lake Erie Prices with Other Known Prices

In Table 21, the Lake Erie prices which result from multiplying the estimated costs by 1.25 are compared with actual national average prices for various kinds of gas (interstate, intrastate, LNG, and SNG). Current prices are generally listed as quoted in the Monthly Energy Review (U.S. Dep. Energy 1978b) and are for the year 1976-1977.

There is an inherent minimum potential error of ± 10 percent in all of the numbers in Table 21. This is primarily due to attempts to escalate (or deflate) reference prices given for years other than 1977-1978. The adjustment factor used was 6.5 percent per year. There are probably other errors as well due to interpretation of pricing labels in references.

As Table 21 shows, Lake Erie gas is competitive (on a wellhead price basis, $1.50-$2.50 per MCF) with imported liquid natural gas, propane, and butane. It would be marginally competitive with current intrastate gas and imports from Mexico and Canada.

The relationship of projected wellhead prices for Lake Erie gas to known similar prices indicates that the economic potential for its development is marginal. Current wellhead prices for onshore gas produced within the three states (Ohio, Pennsylvania, New York) that could claim gas from Lake Erie are 40 to 60 percent lower than the estimated price for Lake Erie gas and 25 percent less than estimated costs. If transmission and distribution costs could be minimized by going directly from the Lake into existing distribution networks immediately adjacent to the Lake, the potential for exploitation would be improved, particularly for Ohio and New York counties adjacent to the shore. Since Ohio has the largest gas supply curtailment of the three states, it would be expected to benefit the most from increased supplies. The indirect economic benefits from expenditures on drilling, though small compared to the existing economic situation, would also accrue mostly to those counties along the lakeshore including those in Canada.

Table 21. Cost and Price Comparisons for Natural Gas

	Price (¢/MCF in 1977-1978 U.S. dollars)[a]						
	Wellhead			Pipeline		Distribution	
	Cost	Cost[b]	Total	Increment[c]	Total	Increment[c]	Total
Current wellhead price							
Ohio	-	-	140	-	-	-	-
Pennsylvania	-	-	73	-	-	-	-
New York	-	-	120	-	-	-	-
U.S. Lake Erie[d]							
Low price	120	30	150	44	194	114	308
High price	200	50	250	44	294	114	408
National interstate average[c]	-	-	70[e]	44	114	114	228
Foreign prices and imports from Canada and Mexico[c]	-	-	200	-	-	-	-
National intrastate average[c]							
Louisiana	-	-	181	-	-	-	-
Oklahoma	-	-	165	-	-	-	-
Texas	-	-	192	-	-	-	-
Liquified natural gas[f]	-	-	270	-	372[g]	-	420
Propane and butane[c,h]	-	-	253	-	-	-	450[i]
Gas from Alaska[f]	-	-	175	-	-	-	390
Ontario "City Gate" price for all gas[j]	-	-	-	-	141	-	-

[a]MCF = thousands of cubic feet. To convert cubic feet to cubic meters, multiply by 0.02832.

[b]25% tax and profit increment.

[c]Prices quoted are for 1976-1977 and adjusted to 1978 U.S. dollars [data from Monthly Energy Review (U.S. Dep. Energy 1978)].

[d]Low prices correspond to well production of 30 MMCF per year; high prices to 18 MMCF per year.

[e]In 1976, the average wellhead price was reported to be 48¢ in Monthly Energy Review (U.S. Dep. Energy 1978), and 58¢ in Gas Facts (Am. Gas Assoc. 1976). In Gas Facts, the range for the the entire U.S. was 28¢ (Arizona) to 114¢ (Virginia).

[f]Data from Federal Power Commission (1977).

[g]Data from U.S. Department of Energy (1978).

[h]Converted from ¢/gal to equivalent CF @ 95 CF/gal or 95,000 Btu/gal and 1000 Btu/CF; these are wholesale prices, probably equivalent at a level between wellhead and pipeline.

[i]Also a typical price for substitute gas made from naphtha or gasoline.

[j]"City gate" prices refer to situations in which neither the buyer nor the seller is the ultimate consumer. Actually, the $1.41 shown is somewhere between wellhead and pipeline and is for all delivered gas. Lake Erie gas supplied less than 2 percent of Ontario's requirements.

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ECONOMIC ISSUES

Are USLE natural gas resources significantly large, when compared to land-based reserves, to warrant development?

Estimated Lake Erie resources ranging from 15.1 billion m^3 (533 BCF) to 25.1 billion m^3 (888 BCF) represent between 0.2 percent and 0.4 percent of total U.S. proved reserves for 1976 [6.1 billion m^3 (216 TCF) (see Table 14)]. In a subnational natural gas market it is difficult to estimate what portion of known reserves would be exploited before Lake Erie gas exploitation would be economical. According to the 1978 Project Independence Evaluation System (PIES) model, approximately 28.3 billion m^3 (1 TCF) of natural gas would be produced in 1985 as a result of deregulation of price as proposed by Congress (July 1978). It is doubtful that any portion of this additional TCF of natural gas would come from Lake Erie since it is probable that cheaper gas will be found elsewhere. After 1985, depending on how expensive other gas sources were to exploit, Lake Erie gas may begin to enter the gas market. Lake Erie gas resources, as predicted by the production scenario, represent about one percent of the reserves for the 13-state region (Stanford Res. Inst. 1977) (see p. 56). With the maximum exploitation scenario presented in the Economic Overview section, Lake Erie gas resources in each state are significant relative to onshore reserves; i.e., about 67.6, 49.2, and 11.2 percent, respectively, of the onshore reserves of New York, Ohio, and Pennsylvania. These comparisons may overstate or perhaps understate the Lake Erie significance, because onshore reserves are better known than Lake Erie "potential" resources.

It should be kept in mind that the development scenario assumed exploitation of 50-90 percent of the potential resources on the U.S. side of Lake Erie. Resources developed according to this assumption cannot be directly compared to known reserves, unless the assumption were based on actual drilling experience. Because the U.S. side of the Lake has not been explored, comparison may be misleading.

What is the potential for use of Lake Erie reservoirs for gas storage?

It is standard practice in the U.S. gas industry to store gas during low requirement periods (typically in the summer) for use during peaking periods (typically winter). In the entire United States, the amount of natural gas in storage varies from 110 to 170 billion m^3 (4 to 6 TCF), with annual consumption levels of 540 to 570 billion m^3 (19-20 TCF) (U.S. Dep. Energy 1978b).

The Lake Erie storage systems will probably involve small depleted reservoirs in porous and permeable geologic formations. Pressures for reinjection could be high [2-4 MPa (300-600 psi)], but still well below those for pressure-testing pipelines prior to installation. After making appropriate changes in pipeline backflow check-valves, it may prove feasible to reinject natural gas into suitably depleted reservoirs without replacing or adding pipeline. The environmental consequences of reinjecting gas back into depleted Lake Erie

reservoirs must be assessed before a determination of USLE gas storage feasibility can be made.

The potential for underground gas storage under Lake Erie is being evaluated in Canadian waters. Underwater Gas Developers, in fact, has successfully stored gas under Canadian waters. Therefore, it appears that after production from a reservoir has depleted pressure to low values, injection of gas from the onshore compression facilities through existing pipeline networks is feasible. In fact, gas goes back into the reservoirs at very low pressure initially. The potential for underground storage of natural gas under Lake Erie is as open as the potential for finding suitable reservoirs and only drilling will determine that. Additional information or data on gas storage methods being employed by the Canadians is not currently available.

Canadian land-based drilling in southern Ontario for 1975 indicates that at least three drilled holes were suitable for storage (Ont. Min. Nat. Resour. 1977). Logs from these holes indicated intersection of a "pinnacle reef," a geologic formation suited for gas reinjection and storage. All storage in use in Ontario for 1975 was located in one county (Lambton) which was not adjacent to Lake Erie.

In summary, the potential for use of small depleted gas reservoirs for gas storage may be good. However, the potential for storage in reservoirs of large areal extent would appear to be small, primarily due to the tightness of the geologic formations in which the gas occurs (as evidenced by low well production rates). Some sites suitable for storage will probably be found if drilling is permitted.

What alternatives to USLE gas drilling are available?

The alternatives to production of Lake Erie natural gas are (1) stimulation of domestic production through price deregulation (both interstate and intrastate), (2) imports through Canada, Mexico, and Alaska, (3) liquified natural gas imports, (4) Ohio Devonian shale, and (5) synthetic natural gas. Before gas producers turn to the latter two alternatives, Lake Erie gas may be a preferable option economically.

As discussed in the Economic Overview, the alternatives to drilling for gas in Lake Erie are closely associated with the future price of gas sold in the Lake Erie Basin. Because the natural gas industry operates in a regulatory framework of federal control for interstate markets and because the natural regions of gas availability depend on the interstate pipeline system, future availability of natural gas depends, in part, on federal gas policies.

If natural gas continues to be regulated and if Lake Erie gas is also to be regulated, preliminary assessment would indicate that Lake Erie gas would not be economical to produce for use in interstate commerce. The price incentive for production would not exist. The possibility of a regulated gas price is more likley than unregulated prices before 1985. The proposed deregulation of natural gas as agreed to in compromise by the Conference Committee of the House and Senate (July 1978) will allow Lake Erie gas to have an unregulated price in 1985. In an unregulated market, it *may* be produced, but not before 1985.

Alternatives to Lake Erie gas need to be considered in light of subnational natural gas markets. A number of models projecting national natural gas consumption were reviewed. These models provide some basis for assessing the alternatives to Lake Erie natural gas production. None of these models can represent the basis for decisions, but they do indicate evidence about natural gas supply alternatives.

As shown in Table 22, forecasts of four models (including two forecasts of the PIES model) are presented under two conditions: price regulation and price deregulation. Under price regulation, all models predict less supply and consequently less consumption of natural gas. Domestic production is significantly different under regulation than under deregulation; higher prices seem to have a greater impact on stimulating domestic production than on changing overall consumption patterns. Most models indicate a significant increase in domestic production due to price deregulation. According to Table 21 (p.), deregulation may not automatically mean that Lake Erie gas production will be profitable. Other natural gas fields may be more profitable to exploit. For this reason, the alternative to Lake Erie gas may be simply "no action," except for price deregulation to stimulate domestic production in other areas. Lake Erie gas will be more attractive with deregulation, but it may not be sufficiently attractive to encourage immediate production.

As noted in the Economic Overview (see Table 21), the interstate market does not indicate that Lake Erie gas is competitive with current prices. In the intrastate market, however, the estimated wellhead price of Lake Erie gas would be competitive in a number of states at current prices. In Ohio, the most recent wellhead price quoted was $1.40 per MCF* and this is close to the low end of the price range estimated for Lake Erie ($1.50 per MCF), but short of the high price range ($2.50 per MCF).

It is difficult to predict future developments in the intrastate market, because natural gas from Lake Erie would become available only in small quantities about the time that the interstate market is being deregulated. Although Lake Erie gas might be competitive in intrastate markets, there is an additional transportation cost of moving the gas to the end-user. Therefore, intrastate gas prices would be appealing to the end-user only if interstate gas would face future curtailments.

The difference between total supply of gas in Table 22 and production of gas presented in Table 23 represents U.S. reliance on other natural gas sources. These sources are indicated in Table 24. For example, the three principal sources that make up the difference between domestic production and total consumption are: Canadian natural gas, liquified natural gas, and synthetic natural gas. On the basis of price, Lake Erie gas may compete well with synthetic natural gas ($4.50 per MCF; footnote to Table 21). The price range estimated by the authors would also make Lake Erie gas competitive with Ohio Devonian shale gas resources (estimated at $4.12 MCF). Lake Erie gas would also be competitive with LNG ($4.20 per MCF) and Alaskan gas ($3.90 per MCF).

*To convert cubic feet to cubic meters, multiply by 0.02832.

Table 22. Projections of Total Supply (TCF)[a] of Natural Gas, 1985-2000

	With Price Regulation			With Price Deregulation		
Model	1985	1990	2000	1985	1990	2000
PIES 75	22	-	-	24	23	-
PIES 78	20	20	-	20[b]	-	-
WAES	20	20	-	20	-	-
FOSTER	21	20	22	24	25	27
SRI[c]	-	-	-	22	21	24[d]

[a]TCF = trillions of cubic feet. To convert cubic feet to cubic meters, multiply by 0.02832.

[b]Explicitly includes congressional intent to deregulate natural gas by 1985.

[c]SRI model projected data for the years 1986, 1989, and 2001. These projections were included in 1985, 1990, and 2000 for comparative purposes only.

[d]Includes approximately 5.5 TCF of synthetic natural gas and 2.5 TCF imports.

See Table 24 for sources of data.

Table 23. Projections of Total Domestic Production (TCF)[a] of Natural Gas, 1985-2010

	With Price Regulation				With Price Deregulation			
Model	1985	1990	2000	2010	1985	1990	2000	2010
PIES 75	18	-	-	-	22	-	-	-
PIES 78	17	16	-	-	18	-	-	-
WAES	16	14	12	8	19	19	14	9
FOSTER	18	17	17	-	21	21	21	-
SRI[b]	-	-	-	-	20	19	16	10

[a][illegible] = trillions of cubic feet. To convert cubic feet to cubic meters, [illegible] by 0.02832.

[b][illegible] "free-market" model.

[illegible] for sources of data.

Table 24. Projections of Total Supply of Natural Gas from Nondomestic or Synthetic Sources, 1985 and 1990

Model	Imports (TCF)[a] Canadian 1985	Canadian 1990	Liquified Natural Gas 1985	Liquified Natural Gas 1990	Subtotal 1985	Subtotal 1990	Synthetic Natural Gas Production (TCF)[a] 1985	Synthetic Natural Gas Production (TCF)[a] 1990
With Price Regulation								
PIES 75	0.9	-	2.1 max	-	3.0	-	1	-
PIES 78	0.9	0.9	0.9 (1.4 max)	1.6 (2.0 max)	1.8	2.5	1	1
WAES	not estimated separately				3	5	1	1
FOSTER	0.9	0.9	0.6	1.0	1.5	1.9	1	1.2
SRI	-	-	-	-	-	-	-	-
With Price Deregulation								
PIES 75	0.9	-	0.4	-	1.3	-	1	-
PIES 78	0.9	-	0.4	-	1.3	-	0.5	-
WAES	not estimated separately				1	1	1[b]	1.2[b]
FOSTER	0.9	0.9	1.0	1.7	1.9	2.6	1	1
SRI[c]	not estimated separately				1.6	1.8	0	0.5

[a]TCF = trillions of cubic feet. To convert cubic feet to cubic meters, multiply by 0.02832.

[b]Synthetic natural gas commitment implies a reduction of 1 TCF from some unspecified source.

[c]Synthetic natural gas from coal only.

Sources of data for projections of total supply and production of natural gas:

Model	Source	Type of Data	Location of Data
1975 PIES Model (Project Independence Evaluation System)	1976 National Energy Outlook, Federal Energy Administration, FEA-N-75/713, February 1976	Quantities	pp. 131-161, G-1, G-2, G-12, G-13, G-24, G-25
1978 PIES Model (Project Independence Evaluation System)	An Evaluation of Natural Gas Pricing Proposals, Analysis Memo AM/IA-7802, Energy Information Administration, 1978	Domestic gas quantities	pp. 164-165
		Synthetic natural gas quantities	pp. 164-165
		Import quantities	Table I-1
		Shortages	Table III
		Prices	Tables IV, X, D-1
	Annual Report to Congress, Vol. II, 1977, Energy Information Administration	Domestic gas quantities	Tables 7.5, 7.6
		Synthetic natural gas quantities	Tables 7.5, 7.6
	PIES Printouts	Domestic gas quantities	Table 8
		Synthetic natural gas quantities	Table 8
		Prices	Table 20
WAES Model (World Atlantic Energy Strategies)	Energy Supply to the Year 2000, WAES, 1977, McGraw-Hill, New York	Domestic gas quantities	pp. [illegible]
		Synthetic natural gas quantities	pp. [illegible]
	Energy Supply-Demand Integrations to the Year 2000, WAES, 1977	Import quantities	pp. [illegible]
FOSTER Model	Fuel and Energy Price Forecasts, Volume 1 Report, Foster Associates, Inc., Washington, D.C., for Electric Power Research Institute, Palo Alto, Calif., EPRI EA-411 (Vol. 1), April 1977	Domestic gas quantities	Vol. 1, p. III-70
		Import quantities	Vol. 1, p. III-70
		Synthetic natural gas quantities	Vol. 1, p. III-70
	Fuel and Energy Price Forecasts, Final Report, Volume 2, Data Base, Stanford Research Institute, Menlo Park, Calif., EPRI EA-433 (Vol. 2), February 1977	Prices	Vol. 2, pp. 67, 69
SRI Model	Fuel and Energy Price Forecasts: Quantities and Long-Term Marginal Prices, Final Report, Volume 1, SRI International, Menlo Park, Calif., for Electric Power Research Institute, Palo Alto, Calif., EPRI EA-433 (Vol. 1), September 1977	Quantities	Vol. 1, pp. 2-4, 2-11, 3-6, 3-7
		Prices	Vol. 1, pp. 2-13, 2-30

On the basis of price and profit, there is less certainty about the competitiveness of Lake Erie gas compared to Canadian imports. Canadian imports are likely to be cheaper than Lake Erie gas, but face transportation problems in reaching the Lake Erie Basin. It should be noted, however, that with deregulation and with the assumption that supplies of natural gas are adequate nationally, there is no reason for any of the foreign imports to physically reach the Lake Erie Basin.

The discussion of alternatives is not as clear-cut in reality as simplified models would indicate. Without exploratory drilling, the location and magnitude of U.S. Lake Erie gas reservoirs will remain uncertain. Based on known reservoir characteristics from Canadian drilling experience, gas reservoirs under the U.S. portion of the Lake are expected to have a wide range of production potentials. Consequently, staged exploitation of the Lake, depending on the quality of reservoirs and offered prices, must be kept in mind as a more realistic approach than any other alternative. For example, it is possible for natural gas users to purchase natural gas through Federal Power Commission (FPC) Order 533 on a "self-help" basis. (Order 533 allows gas users to acquire new gas supply by their own efforts.) If the gas is not for sale or resale, such gas can be consumed without regulation by FERC. However, self-help resources are expensive, requiring sizable investments for exploration, drilling, and transportation of the gas to the end-users.

A sample of gas intensive industries in the ten-county area revealed that most companies have not considered the potential use of Lake Erie gas on a self-help basis. Furthermore, utility companies servicing the area are assuring major end-users that adequate supplies of gas will be available for at least five to ten years (assuming no unusually severe winter conditions). Considering the expense of self-help measures and assurances of adequate supplies from the distribution companies, many gas intensive industries do not consider Lake Erie gas as a viable alternative to any future gas shortage.

It is likely that multiple efforts representing alternatives to Lake Erie gas will be undertaken. No one alternative can be held up as a clear example of a step toward or away from Lake Erie exploitation. Even the self-help regulatory promotion by FERC may not be productive when natural gas is deregulated. If the user industries can rely on higher gas prices to encourage increased natural gas production, then the users may very well abandon self-help efforts.

Will gas produced through USLE operations be used within the tri-state boundaries?

Assuming the deregulation of natural gas prices, there will be no incentive to make more than the minimal required investment in new pipelines. Natural gas from Lake Erie will most likely be directed to one of the three principal pipeline companies serving the basin. These three companies--East Ohio Gas, Columbia Gas of Ohio, and National Fuel Gas Distribution Corporation--will then distribute gas to the user.

If there is a natural gas shortage, gas will be delivered according to priorities established by FERC. Consequently, there is no guarantee that the gas produced in Lake Erie will be used in the counties adjacent to the Lake.

Ohio, Pennsylvania, and New York have their share of "priority" customers and should not have to take a disproportionate amount of curtailments. It may be argued, however, that Ohio did suffer a disproportionate reduction during the winter of 1976-1977. As noted in the Economic Overview (see Table 16), a number of Ohio users were curtailed in the 1976-1977 winter season. To the extent that Lake Erie gas puts more gas into the East Ohio Gas and Columbia Gas of Ohio pipelines, these industries should benefit from the development of Lake Erie gas.

Will the overall economic impact of USLE gas development and production be significant and will the addition of Lake gas to existing supplies alleviate industrial and commercial curtailments that may occur in the future?

The significance of Lake Erie gas can be judged in several ways. At the national level or tri-state level, gas production in Lake Erie would not be a significant source of new gas. Significance is judged purely on the basis of the volume produced relative to consumption. For example, Lake Erie would supply no more than 0.2 percent of U.S. demand in any one year, assuming that current estimates of recoverable assets are reasonably accurate.

With an adequate gas supply, Lake Erie gas production will not be sizable enough to affect the price of gas to users in an unregulated market. In the event of industrial curtailment, the gas could be used to supplement existing supplies. Compared to total annual deliveries to the ten-county area surrounding the Lake, potential USLE average annual production could supply somewhere between 20 and 40 percent of deliveries in a given year. These numerical comparisons do not mean the users in the ten-county area would get the gas if curtailed. Determination of which firms would ultimately receive the gas would be based on FERC priority for interstate gas and on individual state gas allocation policies for intrastate gas.

Another measure of significance is the duration of gas availability. U.S. Lake Erie gas production potential is estimated at 15-25 billion m^3 (533 to 888 BCF) over a 22-year period in the maximum development scenario (Table A.4, Appendix A). Although this volume of gas could be produced from Lake Erie over a 30 or 40 year period, the resource will ultimately be depleted. As the production period is spread out over time, the contribution of Lake Erie gas to any one year's end-user consumption will decrease. The Lake resources could be exploited so as to produce half of the gas estimated in the numerical examples cited. Less exploitation would mean that more gas would be available at a later date. At present, there is no basis for saying that Lake Erie gas will be of greater *economic* benefit, in the long run, if it is exploited immediately or if it is left in the ground for some distant future recovery.

Given the costs of Lake drilling, compliance with environmental regulations, and questionable production capacity, will profits be great enough to encourage U.S. involvement in Lake Erie gas development?

With current price regulation, there is no incentive to exploiting Lake Erie gas on an interstate basis. With the expectation of natural gas deregulation after 1985, the incentive is uncertain. Many larger gas resources exist in the United States and these will probably be sought and exploited before Lake Erie gas resources are explored. Undoubtedly, there will be

exploitation of reserves in other parts of the United States that hitherto would not have provided a sufficient return on investment.

Because Lake Erie gas leases would be new, smaller companies with few existing reserves to exploit may find Lake Erie attractive. Although the Canadian experience shows that wells are small producers [510,000 m^3 and 850,000 m^3 (18 to 30 MMCF) per year], it also shows that the Lake is not an unduly risky place in which to find gas (65 percent success rate). Moreover, the drilling technology currently being used on the Lake has been proven elsewhere under much more difficult offshore operating conditions. Thus, although Lake Erie may be considered a marginal venture from the overall industry point of view, it may be a good place to develop gas resources for individual operators, and particularly those already working on the Canadian side.

What are the reasons for state and local governments to encourage Lake Erie gas development?

The principal incentive encouraging Lake Erie gas development is the potential for increasing supplies to industrial gas users through the pipelines that serve the basin. Although such exploitation can neither guarantee that the users will get the gas when they need it nor that the gas will be consumed in the state of origin, Lake Erie gas production is a step in that direction.

Royalty returns to the states would not be large. At ten percent of the low range of annual production predicted by the scenario, 680 million m^3 (24 BCF), the three states would share $4.8 million dollars per year at a price of $2.00 per MCF and $9.6 million dollars at twice the price. The states would also collect fees for permits and other rights; presumably these additional revenues would reflect services rendered by the states to the drilling companies.

At 10 percent of the high range of predicted annual production, 1.1 billion m^3 (40 BCF), the three states would share $8.0 or $16.0 million for a price of $2.00 or $4.00 per MCF, respectively.

The maximum development scenario described in the Economic Overview shows a maximum direct employment of 1000 people through the last 13 years of production. This estimate reflects direct employment from Lake Erie gas development. No multiplier effects have been estimated for this industry, but the likely multiplier range may be from 1.5 to 3.0 (staff estimate). Total annual employment directly or indirectly due to Lake Erie exploitation might then range from 1500 to 3000 people. These estimates are in no way based on the Canadian experience. A study of the Canadian experience would have to be undertaken to arrive at a U.S. employment estimate, which is at present no more than an educated guess.

The exploitation of Lake Erie gas would also have a direct expenditure impact on the three states of the Lake Erie Basin. Canada may also benefit by exploitation of the U.S. side of the Lake. Direct investment when production starts (under the maximum development scenario) is expected to be from $40 to $60 million annually. There is no basis for estimating how the three states and Canada would share these economic benefits.

As with employment multipliers, this direct investment will result in expenditure multipliers. A likely range of expenditure multipliers is from 2.0 to 4.0 (staff estimate) which would result in total increased expenditures of $80 to $240 million annually. Again, study of the Canadian experience would yield estimates based on actual data rather than educated guesses.

Will Lake Erie gas be developed at prices to the consumer that will benefit consumers and citizens in states adjacent to Lake Erie?

Both supply and government regulation can influence the price of natural gas. With gas deregulation, the overall price of natural gas will increase. Because lake resources are small, the proportion of gas price increase attributable to Lake Erie development will be imperceptible. Initially, Lake Erie gas would be sold at the same price as all newly discovered gas in new fields--$1.94 per MCF in 1980. This price, as considered by Congress, is $1.75 per MCF (1977) inflated at 3.5 percent per year to 1980 in 1977 dollars. This price is greater than an average interstate price (1977) of $0.75 per MCF and is within range of intrastate prices of $0.90 to $2.19 per MCF.

The impact of these higher prices on the consumer will be greater if users are forced to pay the "incremental" price of "new" gas rather than if they pay a "rolled-in" gas price. (Incremental price is the actual price to produce new gas; rolled-in price is the price of new gas averaged into the price of all other gas.) Any time new gas is rolled in or averaged into the existing price structure, the impact on consumer prices is minimized.

If deregulation results in significant increases in domestic production, such production will have a steadying effect on future price increases. The amount of new domestic production expected by 1985 is described in the discussion of alternatives to Lake Erie gas. Because supplies take time to develop, the impact on price due to deregulated production in 1985 is not expected to be more than a few cents per MCF.

It is likely that residential consumers would be willing to pay higher gas prices rather than pay the high capital costs required to switch to alternate fuels (oil or coal). For commercial and industrial customers, gas availability and capital costs of switching become important considerations in the ultimate choice of fuel. These considerations are described as follows. At the higher price of $1.94 per MCF natural gas is still competitive and usually cheaper than distillate oil or residual oil on a price per Btu basis. The United States has much more control over the future price of natural gas than oil. Natural gas prices will likely be higher than coal on a Btu basis, but the environmental cost of natural gas is lower. Much of this environmental cost comes in the form of air pollution control equipment. New capital expenditures on boilers would also be required which raises the overall cost of using coal to equal to or greater than natural gas. The capital cost of switching to alternate fuel is prohibitive to residential users, and where it can be undertaken by industry, conversion to coal may still be more expensive than burning oil or natural gas.

The compromise natural gas bill worked out by the House and Senate Conference Committee represents about a 50 percent increase in wellhead gas price over what current legislation would have permitted (U.S. Dep. Energy 1978a).

Using a ratio of wellhead to end-use price of 0.6/1.6 = 37.5 percent, (Am. Gas Assoc. 1976), the price impact to industry may be calculated as 0.5 × 0.375 = 0.2 resulting in 20 percent higher prices. The higher price to the consumer should be less than 20 percent (probably less than 10 percent) because fuel cost is only part of the residential customer's utility bill. The impact on product prices will probably not be noticed by the consumer.

Natural gas prices, as all fuel prices, will be increasing anyway due to demand and inflation. Higher prices will be noticed, but they cannot necessarily be attributed to gas deregulation.

In calculating the impact of price deregulation on the consumer, the Project Independence Evaluation System model predicted that residential users would face price increases of about six percent (1985) over what current legislation allows, and industrial customers would face price increases of about 13 percent (U.S. Dep. Energy 1978a). These increases reflect the price impact that could be attributed to deregulating the price of natural gas. As evident, there is no major price increase from natural gas deregulation in the short run. Over the longer run, the price of natural gas will depend increasingly on new supplies and on how easily (at what price) and in what quantities they are found.

The compromise legislation proposed by Congress forces the newer and higher priced gas to be paid for by industry for the most part. Consequently, the higher priority residential customers are insulated from rising gas prices. Because Congress requires industry to pay for the "incremental" cost of gas, the residential customer primarily pays for gas located in already discovered reservoirs.

The overall national picture of gas pricing overshadows the impact of Lake Erie gas. From the economic viewpoint of the consumer, Lake Erie development will have virtually no impact on gas prices. There may be an increased supply by a very small amount. From the viewpoint of the citizen, the benefits of exploitation depend on whether the benefit from an increase in natural gas supply is worth the increase in environmental cost associated with exploitation.

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INSTITUTIONAL OVERVIEW

The primary institutional challenge facing the extraction of gas from under Lake Erie is not the development of a regulatory framework but the application of an existing framework to a new situation. Present laws for the protection of water, land, and air resources impact upon almost every stage of a drilling operation. Each of the states adjacent to the Lake administers a regulatory program for drilling on land. Nevertheless, the unique circumstances that accompany drilling in fresh water may require special attention.

Three levels of government--international, national, and state--will have jurisdiction over drilling in the Lake. Responsibilities have been delegated to a large number of agencies. A brief discussion of these agencies will be presented to identify their potential role in a gas drilling program.

INTERNATIONAL AUTHORITY

The Boundary Waters Treaty of 1909 between the United States and Great Britain (Canada)* was primarily envisioned as a means for settling potential controversies over the use of the Great Lakes area (Comment 1973). Its original focus was protection of the water levels and navigability of the Great Lakes and associated waters. A more recent concern within the provisions of the 1909 Treaty has been transnational pollution.

The International Joint Commission (IJC) received its mandate from Article VIII of the treaty. The IJC is composed of six commissioners, three each from Canada and the United States. It maintains a modest permanent staff, and draws upon personnel from each country as the need arises (Bilder 1972). Permanent offices are maintained in Washington and Ottawa, and meetings are held at least semiannually (Int. Joint Comm. 1965).

The 1909 Treaty gave the IJC responsibility in two areas. First, under Articles II, IV, and VIII, the commission can approve or disapprove applications for the use, obstruction, or diversion of boundary waters, on either side, which would affect boundary water levels or flow. This is essentially a regulatory or licensing function. It is initiated when permit "applications" are filed by public agencies, private corporations, or individuals (Int. Joint Comm. 1965).

The second general responsibility of the IJC is covered under Article IX of the 1909 Treaty. Upon request by either or both governments, the IJC is to

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*"Treaty Between the United States and Great Britain Relating to Boundary Waters and Questions Arising Between the United States and Canada," January 11, 1909, 36 Stat. 2448 (1910), T. A. No. 548 (hereinafter cited as 1909 Treaty). Canada confirmed the treaty by an Act of Parliament in 1911. (1-2 Gro. 5, C.58 Assented to May 19, 1911. Amended 1914, 4-5 Geo. 5, C.5.)

investigate and make recommendations on specific problems. These requests are called "references" (Int. Joint Comm. 1965). Even though the treaty suggests that a single government may make a reference, in practice they have been made jointly or concurrently (Waite 1964). The subject of a reference is not restricted to boundary waters. It may embrace any question or matter of difference between the two countries involving any rights, obligations, or interests in relation to their common frontier (Bilder 1972). Although the IJC's main interest remains with water quality, lake levels, and navigability, references have been made on an extremely wide range of topics.

Once the IJC receives a reference, it appoints a board of experts from both countries to conduct the required technical investigation. A written report including recommendations is filed with the IJC (Bilder 1972), and public meetings are usually scheduled in the locality concerned. The IJC then prepares its own report and recommendations. Neither government is bound by the recommendations and their acceptance does not imply that further governmental action will be taken. The recommendations of the IJC are morally restrictive and not legally binding.

A recent example of the reference/recommendation process is the Great Lakes pollution study completed in 1970 that led to an agreement between the United States and Canada (Int. Joint Comm. 1970). In 1964, the two governments requested that the IJC investigate the extent, causes, and location of pollution and suggest remedial measures for Lakes Erie and Ontario and for the international section of the St. Lawrence River [Lower Great Lakes Pollution Reference, Int. Joint Comm. Document No. 83 (Oct. 7, 1964)]. Following the normal procedures for a reference, the IJC filed its final report in 1970 (Int. Joint Comm. 1970). On 15 April 1972, the countries signed the Great Lakes Water Quality Agreement.* Referring to both the 1970 pollution report and the 1909 Boundary Waters Treaty, the agreement stipulates maximum permissible levels for a number of pollutants and provides general guidelines for others.

The Water Quality Agreement also enlarged the role of the IJC to include the following responsibilities: collecting, analyzing, and disseminating relevant data and information; investigating water quality in the Great Lakes; monitoring the effectiveness of government programs to achieve common water quality objectives; coordinating activities to improve quality; and recommending legislation and programs. Article VII established a Great Lakes Water Quality Board which was to assist the IJC in the exercise of its powers and responsibilities.

At this time, the two countries are in the final stages of developing a new Great Lakes Water Quality Agreement. The new agreement sets far more comprehensive and stringent specific limits on pollution and will be applied to the entire Great Lakes Basin (Bureau of National Affairs 1978a). It also established a new section on toxic substances control with an appendix naming 250 hazardous substances drawn from the EPA's list of toxic chemicals under § 311 of the Clean Water Act [see 43 Fed. Reg. 10481-10488 (1978)]. This

*"Agreement Between the United States of America and Canada on Great Lakes Water Quality," 23 U.S.T. 301, T.I.A.S. No. 7312 (1972).

section makes it easier for the governments to add new substances to the list. It also seeks to eliminate discharges of 32 "persistent" toxic substances, i.e., those having a half-life in water of over eight weeks (Bureau of National Affairs 1978a).

The signing of this agreement has been delayed by the Office of Management and Budget until EPA can report on whether the United States would need new legislation and how much the new control program will cost (Bureau of National Affairs 1978b). Since the Water Quality Agreement is not a treaty and does not have force of law, it must be implemented by each country's existing environmental regulations.

FEDERAL AUTHORITY

Although many federal agencies (e.g., Fish and Wildlife Service, Department of Energy, and National Oceanic and Atmospheric Administration) are involved with different programs affecting the Lake, four federal agencies can be identified which would be directly involved if gas were developed under Lake Erie: the Army Corps of Engineers, the Environmental Protection Agency, the Department of Transportation, and the Coast Guard. The national interest in shipping and protecting the environment would provide basic reasons for the involvement of the federal government.

Corps of Engineers

Under the Rivers and Harbors Act of 1899 (33 USC § 403), the U.S. Army Corps of Engineers (COE) has traditionally held permitting authority over all obstructions to navigable waters. Permits have been required for oil rigs on the outer continental shelf (Cowles 1976) and objects that are completely submerged [33 CFR § 322.3 (a)(1)]. Permit applications are evaluated by a balancing process that exhibits concern for both the protection and utilization of resources [33 CFR § 320.4 (a)(1)]. Factors to be considered include economics, aesthetics, environmental concerns, historic values, fish and wildlife values, land-use classifications, navigation, recreation, water supply, and water quality [33 CFR § 320.4 (a)(1)]. The final permit, if approved, may include specific conditions or stipulations reflecting these considerations [33 CFR § 325.5 (a)(2)].

Other federal and state agencies play an important role in the COE permitting process. The COE District Engineer is required to consider recommendations from relevant officials in the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, the Environmental Protection Agency, the Soil Conservation Service (Department of Agriculture), and the counterpart state agencies [33 CFR § 320.4 (b)]. The U.S. Fish and Wildlife Service may review each permit pursuant to the United States Fish and Wildlife Coordination Act (16 USC § 661) and a Memorandum of Understanding (13 July 1967) between the secretaries of the interior and the army (see Cowles 1976). Finally, no permit will be issued where certification of the proposed work is required by state or local law and certification has been denied [33 CFR § 320.4 (j)(6)].

COE permits are also required for the discharge of dredged or fill materials to navigable waters [Federal Water Pollution Control Act Amendments of

1972 (FWPCA), Pub. L. 92-500, § 404, 33 USC § 1344 (as amended by Clean Water Act, Pub. L. 95-217)]. Regulations concerning these activities have been developed in conjunction with EPA (33 CFR § 323; 40 CFR § 230). The balancing criteria and the attention given interagency recommendations in the dredged and fill-material discharge permitting program are identical to those in the obstructions program. The EPA does, however, have the power to prohibit specific discharge sites after a determination that the operations will have an unacceptable impact on municipal water supplies, fisheries, wildlife, or recreational areas [33 USC § 1344 (c)].* The dredged and fill-material permitting program for certain waters not presented in this study, may be taken over by a state with EPA approval [33 USC § 1344 (g)].

Environmental Protection Agency

The Environmental Protection Agency (EPA) was created in Reorganization Plan No. 3 of 1970 [40 CFR § 112.7 (e) (7)]. Included among its responsibilities is authority over the federal air and water quality programs.

Clean Water Act

The groundwork for today's water quality program was established by the Federal Water Pollution Control Act Amendments of 1972 (Pub. L. No. 92-500, 86 Stat. 816, 33 USC §§ 1251-1376). This important legislation has since been amended by the Clean Water Act of 1977 (Pub. L. No. 95-217, 91 Stat. 1566). These acts establish a two-sided regulatory scheme of effluent and water quality standards that is designed to ensure fishable, swimmable waters by 1983. Standards promulgated or approved by EPA are applied to individual point sources through permits issued under the National Pollutant Discharge Elimination System (NPDES) (33 USC § 1342). Permits are granted by the EPA regional administrator or by the director of an approved NPDES state program. Each of the states adjoining Lake Erie has an approved NPDES program.

The first part of the regulatory program establishes technology-based effluent standards for industrial and municipal discharges (33 USC § 1311). These standards are designed to limit concentrations of specified pollutants that may be discharged from a given point source over a given period of time. The Clean Water Act creates three separate classes of pollutants: conventional, nonconventional, and toxic. The level of control technology that an industrial discharger will be required to apply varies according to the classification of the pollutant concerned.

The Clean Water Act orders EPA to publish "information identifying conventional pollutants, including but not limited to pollutants classified as biological oxygen demanding, suspended solids, fecal coliform, and pH" [33 USC § 1314 (a)(4)]. It has been proposed that chemical oxygen demanding substances, phosphorus, and oil and grease be added to the list [43 Fed. Reg. 32857 (1978)]. As of 1 July 1977, a best practical control technology (BPT) standard has been applied to discharges of conventional pollutants [33 USC § 1311]. A more stringent best conventional pollutant control technology (BCT) standard is to be used after 1 July 1984 [33 USC § 1311 (b)(2)(E)].

*EPA regulations promulgated under this section are currently being revised.

The second classification, nonconventional pollutants, includes everything not defined as conventional or toxic. Like conventional pollutants, this class is presently subject to the BPT standard. In the future, the relevant standard will be the best available technology economically achievable (BAT) (33 USC § 1311). The BAT standard need not be met until 1 July 1984 or until three years after effluent limitations are established, whichever is later. In no case may that date be later than 1 July 1987 [33 USC § 1311 (b)(2)(F)]. Under certain conditions, however, the EPA administrator may modify the BAT effluent limitation, making it less stringent. Among the factors to be considered is the quality of the receiving waters [33 USC § 1311 (g)].

Toxic pollutants, as defined by the act, are those which will cause death, disease, cancer, or physical, behavioral, or genetic abnormalities in any organism or its offspring [33 USC § 1362 (13)]. At a minimum, discharges of these substances are subject to BAT, and additional and even more stringent standards might be created separately for an individual chemical [33 USC § 1317 (a)]. The Clean Water Act requires the EPA administrator to compile a list of toxics starting with 65 specified chemicals [33 USC § 1317 (a)(1); see H. R. Comm. Print No. 30, 95th Cong., 1st Sess. (1977)]. Effluent standards and ambient water criteria will be established for each substance on the list. If the effluent standards will not guarantee ambient water criteria because of local water conditions, the permitting authority may impose more stringent standards [42 Fed. Reg. 2588 (1977)].

Effluent standards reflecting these requirements have been established on an industry-by-industry basis. The relevant standards for gas drilling in Lake Erie are those pertaining to the Oil and Gas Extraction Point Source Category (40 CFR § 435). Under the interim final effluent limitation guidelines, Lake Erie has been placed in the onshore subcategory (40 CFR § 435.30). As such, there can be no discharge of wastewater pollutants into navigable waters [40 CFR § 435.32 (a)]. These guidelines are undergoing revision, however, and it appears that the Great Lakes will be transferred to the coastal subcategory (Horvatin 1978--personal communication). The BPT limitations which presently apply to the coastal subcategory are given in Table 25.

The second major section of the regulatory program of the Clean Water Act involves ambient water quality standards. These standards serve as the basis for determining NPDES permit effluent limitations for pollutants which are not addressed in the effluent guidelines or for pollutants for which the effluent guidelines are not stringent enough to protect desired water uses. Federal standards are based on water quality criteria as published by the EPA; criteria are designed to reflect the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare which may be expected from the presence of pollutants in any body of water, including groundwater (USEPA 1976). Under the authority of the act, state water quality standards are evaluated for compliance with federal standards [33 USC § 1313 (b)]. The state's standards may be more stringent, although they may not be less stringent. This fact allows IJC policy to be incorporated into state regulations. The EPA has approved the water quality standards of each of the states bordering Lake Erie [42 Fed. Reg. 56786 (1977)]. (For citations to state water quality standards, see Table 26.)

Table 25. Proposed Effluent Limitation Guidelines for the Oil and Gas Extraction Industry[a]

Pollutant Parameter, Waste Source	Effluent Limitations (μg/mL): Oil and Grease: Maximum for Any 1 Day	Oil and Grease: Average of Daily Values for 30 Consecutive Days Shall Not Exceed	Residual Chlorine: Minimum for Any 1 Day
Produced water	72	48	-
Deck drainage	72	48	-
Drilling muds	b	b	-
Drill cuttings	b	b	-
Well treatment	b	b	-
Sanitary:[c] M10	-	-	1[d]
M91M[e]	-	-	-
Domestic[f] produced sand	b	b	-

[a]For the coastal subcategory. The same limitations apply for the near-offshore subcategory (40 CFR § 435.10).

[b]No discharge of free oil.

[c]The term M10 refers to those offshore facilities continuously manned by ten or more persons. The term M91M refers to those offshore facilities continuously manned by nine or less persons or intermittently manned by any number of persons.

[d]Minimum of 1 μg/mL and maintained as close to this concentration as possible.

[e]There shall be no floating solids as a result of the discharge of these wastes.

Source: 40 CFR § 435.40.

The Clean Water Act supplements the NPDES permitting program with the areawide waste treatment management program as established under Section 208 [33 USC 1288]. State governors are given the power to designate areas within their states that have substantial water quality problems. A planning agency, including local governmental officials, is then created for each designated area, and is required to develop an areawide waste treatment management plan within three years of its creation. The state retains Section 208 planning responsibilities in all areas that are not specially designated. Among the requirements to be met by a Section 208 plan is the establishment of a program to regulate the location, modification, and construction of facilities within the area "which may result in any discharge in such area" [33 USC § 1288 (b)(2) (C)(ii)]. This program could have a large impact upon gas drilling in Lake Erie.

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AN EXAMINATION OF ISSUES RELATED TO U.S. LAKE ERIE NATURAL GAS --ETC(U)
SEP 78 D L MCGREGOR, J G FERRANTE, R K RODIEK EPA-P-7808A

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2 OF 3

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It should be noted that the term "pollutant," as defined in the Clean Water Act, does *not* include *"water, gas, or other material which is injected into a well to facilitate production of oil or gas, or water derived in association with oil or gas production and disposed of in a well, if the well used either to facilitate production or for disposal purposes is approved by authority of the State in which the well is located, and if such State determines that such injection or disposal will not result in the degradation of ground or surface water resources"* [33 USC § 1362 (6)]. To clarify its position with respect to this provision, EPA has issued a policy statement regarding well injection which opposes subsurface injection without "strict controls" and a "clear demonstration" that there will be no environmental damage (USEPA 1973). Moreover, subsurface injection as a means of waste disposal is viewed as a temporary expedient to be used only until newer and more protective technology becomes available.

Two other sections of the Clean Water Act grant EPA regulatory authority over portions of a Lake Erie drilling program. Section 311 provides authority for establishing procedures for the prevention and containment of oil discharges [33 USC § 1321 (j)(1)]. The EPA regulations require all non-transportation related offshore facilities that could reasonably be expected to discharge oil in harmful quantities to prepare a Spill Prevention Control and Countermeasure Plan (SPCC) (40 CFR § 112). The plan must be certified by a registered professional engineer [40 CFR § 112.3 (d)]. Numerous special SPCC requirements have been developed with regard to offshore oil drilling [40 CFR § 112.7 (e) (7)]. These may or may not be applied to gas drilling in the Lake. The EPA also has regulatory authority over marine sanitation devices used by commercial vessels on the Great Lakes; a minimum of secondary treatment is required from all such devices [33 USC § 312 (c)(1)(B)].

Safe Drinking Water Act

The Safe Drinking Water Act (42 USC § 300f *et seq*) was designed to protect underground sources of drinking water. The EPA has been directed to develop regulations outlining the nature of the required state underground injection control programs [42 USC § 300h (a)]. A draft regulatory proposal by EPA on 4 August 1978 submits all but presently existing injection wells to stringent permitting procedures. The draft regulations "would enable EPA to bring existing oil and gas waste disposal wells under the area of review requirements at a later date" (Bureau of National Affairs 1978c).

Clean Air Act

The Clean Air Act of 1970, as amended (42 USC § 1854 *et seq*), was intended to protect and enhance the quality of the nation's air resources (42 USC § 1857). The EPA has been given the authority to promulgate primary and secondary ambient air quality standards, and this has been done for certain major pollutants (Evans 1976). These standards are to be applied to polluters by the states. Under § 110, EPA has the authority to develop all or part of an implementation plan if the EPA administrator is not satisfied with the state's plan (42 USC § 1857).

Department of Transportation

Under the Natural Gas Pipeline Safety Act of 1968 (49 USC §§ 1671-84), the secretary of transportation has established minimum federal safety standards for pipeline facilities and the transportation of gas (49 CFR §§ 190.1 *et seq*, 192 *et seq*). These regulations control the design, construction, installation, operation, replacement, maintenance, and inspection of all interstate pipeline facilities. Violations may be attacked through court injunction or punished by fine (49 USC §§ 1678-79). The secretary may also waive, in whole or in part, compliance with any safety standard after an opportunity for a hearing [49 USC § 1672 (e)].

Subject to certain conditions, jurisdiction over intrastate gas pipelines has been retained by the states [49 USC § 1672 (b)]. Standards of pipeline safety established by state agencies must, however, be at least as stringent as those promulgated by the secretary of transportation [49 USC § 1672 (b)]. The state programs must also receive annual certification from the secretary. To receive certification, the state agency must show: (1) that it has regulatory jurisdiction over safety standards, (2) that it has adopted federal standards, (3) that it is enforcing each such standard, (4) that it is promoting programs devised to prevent pipeline damage during excavation activities, and (5) that it has the authority to monitor and enforce all regulations [49 USC § 1674 (a)].

Coast Guard

The Coast Guard is involved in numerous Lake activities through its responsibilities concerning navigation. Lighting, marking, and buoying requirements have been developed that would apply to rigs and support vessels alike (see generally 14 USC § 81 *et seq*; 33 CFR §§ 60-67). Under the Ports and Waterways Safety Act of 1972 (33 USC §§ 1221-1227), the Coast Guard is empowered to protect navigable waters from environmental harm resulting from damages to or destruction of vessels and structures. Specifically, the Coast Guard may: (1) control vessel traffic in especially congested or hazardous areas or during adverse weather conditions, (2) establish standards for the handling of dangerous substances, and (3) establish safety zones of limited, controlled, or conditional access (33 USC § 1221). Safety zones have been created in the vicinity of drill rigs on the outer continental shelf [42 Fed. Reg. 63368 (1977)]. Regulations controlling the handling and transportation of inflammables, corrosives, compressed gasses, poisons, and hazardous substances are also authorized by the Tank Vessel Act (46 USC § 391a) and the Dangerous Cargo Act (46 USC § 170). Finally, the Coast Guard has the authority to inspect and regulate vessels to protect the safety of passengers and crew (46 USC § 390a).

Another important Coast Guard duty is to respond to accidents. Under the FWPCA [32 USC § 1321 (j)(1)], authority has been granted to respond to pollution incidents in the coastal waters of the United States including the Great Lakes [Exec. Order No. 11735, 38 Fed. Reg. 21243 (1973)]. Coast Guard regulations require notification following an unauthorized discharge of oil or a hazardous substance from vessels, onshore facilities, or offshore facilities (33 CFR § 153.203). Fines of up to $10,000 may be assessed if proper

notification is not given (33 CFR § 153.205). As soon as the Coast Guard has knowledge of a spill on the Lake, it implements the National Oil and Hazardous Substances Pollution Contingency Plan (see p.) (40 CFR § 1510). The purpose of the plan is to insure that timely and effective action is taken to control and remove all discharges into or upon the Lake.* Unless the pollutant is being effectively removed by the party responsible, the on-scene coordinator appointed by the Coast Guard will recommend and supervise federal and state pollution control efforts (40 CFR § 1510.36). Special equipment has been purchased and distributed across the nation.* Private contractors could be engaged as needed. Whenever possible, the party will be made to pay for clean-up costs and for any damage done to federal, state, or local government property (40 CFR § 1510.45). A punitive fine of up to $5,000 might also be assessed [33 CFR 153.105 (a)(1)].

STATE AUTHORITY**

Authority over the land beneath Lake Erie is vested in the adjacent states: New York, Ohio, and Pennsylvania.† The legislatures of each of these states have delegated their power to lease the land to appropriate state agencies. Leasing rights will be limited to the exploration, development, and production of gas.

All three states have conservation and environmental legislation that is potentially relevant. Many aspects of the drilling process, from boring the initial hole to abandonment, are regulated. Controls are placed on pipelines, as both New York and Ohio have agencies that review pipeline siting plans to minimize adverse environmental impacts. Depending on the state, water obstruction or dredge and fill permits complementary to those required by the Corps of Engineers might be required prior to setting the rig or laying pipelines. Authority over water quality, air quality, and waste disposal has been vested in a single agency in each of the states. Additional laws provide for the protection of fish and municipal water supplies. These laws form the nucleus of a regulatory program. Where additional controls are required, they may be added by modifications to present laws and regulations or by inclusion in the lease.

Special mention should be made of two New York laws. The Uniform Procedures Act [N.Y. Envir. Conserv. Law § 70-0101 *et seq* (McKinney)] established a

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*"Coast Guard Efforts to Prevent Oil Pollution Caused by Tanker Accidents." Hearings Before the Subcommittee on Government Activities and Transportation of the House Committee on Government Operations, 95th Cong., 1st Sess., 449-450 (1977).

**Most of the references have been omitted from this section. The relevant legislation will be presented in Table 26.

†State title to the beds of navigable internal waters comes from the English Crown for the original thirteen states [Mumford v. Wardwell, 73 U.S. 423, 436 (1867)], and from the "equal footing doctrine" for the remaining states [Pollard's Lessee v. Hagan, 44 U.S. 212 (1845)].

Table 26. State Laws and Regulations

	New York	Pennsylvania	Ohio
Leasing Program			
Agency	Department of Environmental Conservation (DEC)	Department of Environmental Resources (DER)	Department of Natural Resources (DNR)
Authority	N.Y. Envir. Conserv. Law §23-1101 (McKinney)	71 Pa. Cons. Stat. Ann. §510-2 (6) (Purdon)	Ohio Rev. Code Ann. §1505.07 (Page)
Comment	There is no proposed lease, only a report outlining the antici- pated lease and regulations.	There is a proposed lease.	No action has yet been taken.
Oil and Gas			
Agency	DEC	DER	DNR
Statute	N.Y. Envir. Conserv. Law §23-0101 *et seq* (McKinney)	52 Pa. Cons. Stat. Ann. §1 *et seq* (Purdon) 58 Pa. Cons. Stat. Ann. §2101 *et seq* (Purdon)	Ohio Rev. Code Ann. §1509.01 *et seq* (Page)
Regulations	6 N.Y. Codes, Rules & Reg. §§550-58	25 Pa. Code §79	Ohio Ad. Code §1501:9-1-01 *et seq*
Pipeline Siting			
Agency	Public Service Commission		Power Siting Commission
Statute	N.Y. Pub. Serv. Law §120 *et seq* (McKinney)		Ohio Rev. Code Ann. §4806.01 *et seq* (Page)
Regulations	16 N.Y. Codes, Rules & Reg. §§85-88		Ohio Ad. Code, §4906 *et seq*
Water Quality			
Agency	DEC	DER	Ohio Environmental Protection Agency (Ohio EPA)
Statute	N.Y. Envir. Conserv. Law §17-0101 *et seq* (McKinney)	35 Pa. Cons. Stat. Ann. §691.1 *et seq* (Purdon)	Ohio Rev. Code Ann. §6111.01 *et seq* (Page)
Standards	6 N.Y. Codes, Rules & Reg. §§700-04, 835-39	25 Pa. Code §§91,93	Ohio Ad. Code §3745-1-01 *et seq*
NPDES	6 N.Y. Codes, Rules & Reg. §§750-57	25 Pa. Code §92	Ohio Ad. Code §3745-33-01 *et seq*

Table 26. (Continued)

	New York	Pennsylvania	Ohio
Water Quality (cont.)			
Other Laws	Watercraft Sewage Disposal Law. N.Y. Nav. Law §33-c (McKinney)	Protection of fish 30 Pa. Cons. Stat. Ann. §200 (Purdon)	Watercraft Sewage Disposal Law, Ohio Rev. Code Ann. §1547.33 *et seq* (Page)
	Protection of fish--N.Y. Envir. Conserv. Law §§11-0505, 11-0505 (McKinney)		Protection of municipal water supplies--Ohio Rev. Code Ann. §§715-081, 743.25 (Page)
Air Quality			
Agency	DEC	DER	Ohio EPA
Statute	N.Y. Envir. Conserv. Law §19-0101 *et seq* (McKinney)	35 Pa. Cons. Stat. Ann. §4001 *et seq* (Purdon)	Ohio Rev. Code Ann. §3704.01 *et seq* (Page)
Regulations	6 N.Y. Codes, Rules & Reg. §200 *et seq*	25 Pa. Code §121 *et seq*	Ohio Ad. Code §3745-15-01 *et seq*
Waste Disposal			
Agency	DEC	DER	Ohio EPA
Statute	N.Y. Envir. Conserv. Law §27-0101 *et seq* (McKinney)	35 Pa. Cons. Stat. Ann. §6001 *et seq* (Purdon)	Ohio Rev. Code Ann. §3734.01 *et seq* (Page)
Regulations	6 N.Y. Codes, Rules & Reg. §360	25 Pa. Code §75	Ohio Ad. Code §3745-27-01 *et seq*
Oil Spill Contingency Plan			
Agency	Dep. of Transportation, DEC	DER	
Statute	N.Y. Nav. Law §170 *et seq* (McKinney)	35 Pa. Cons. Stat. Ann. §691.401 *et seq* (Purdon)	
Regulations	17 N.Y. Codes, Rules & Reg. §§30-33		
Obstructions to Navigable Waters			
Agency	DEC	DER	
Statute	N.Y. Envir. Conser. Law §15-0503 (McKinney)	32 Pa. Cons. Stat. Ann. §681 *et seq* (Purdon)	
	N.Y. Nav. Law §32 (McKinney)		
Regulations	6 N.Y. Codes, Rules & Reg. §608	25 Pa. Code §105	

Table 26. (Continued)

	New York	Pennsylvania	Ohio
Dredge and Fill			
Agency	DEC		
Statute	N.Y. Envir. Conserv. Law §15-0505 (McKinney)		
	N.Y. Nav. Law §31 (McKinney)		
Regulations	6 N.Y. Codes, Rules & Reg. §608		
Wetlands			
Agency	DEC		
Statute	N.Y. Envir. Conserv. Law §24-0105 *et seq* (McKinney)		
Regulations	6 N.Y. Codes, Rules & Reg. §662		
Other Laws	Uniform Procedures Act, N.Y. Envir. Conserv. Law §70-0101 *et seq* (McKinney)	Excavation and demolition, 73 Pa. Cons. Stat. Ann. §176 *et seq* (Purdon)	
	Environmental Quality Review Act, N.Y. Envir. Conserv. Law §8-0101 (McKinney)		

consolidated permitting process for certain bureaus of the Department of Environmental Conservation. This means that the potential driller should be able to get most of the necessary New York permits, including the State Pollutant Discharge Elimination System certification, with a single application. The second law, the Environmental Quality Review Act [N.Y. Envir. Conserv. Law § 8-0101 *et seq* (McKinney)], requires state agencies to prepare an environmental impact statement on any action they propose or approve which may have a significant effect on the environment. Federal reports prepared in compliance with the National Environmental Policy Act of 1969 (42 USC § 4321 *et seq*) will satisfy the requirements of the state law, although a more site-specific analysis may be desired.

RECREATIONAL PLANNING

The Land and Water Conservation Fund Act of 1965 (Pub. L. 88-578) establishes federal funds for use by individual states to promote planning and development of recreation resources. To qualify for assistance from the fund, the act requires that a state compile a comprehensive recreation plan promulgating its policies towards various aspects of recreational and open space planning and development.

Pennsylvania and Ohio have recently updated their plans, whereas New York is currently engaged in the preparation of its 1978 plan. Statewide Comprehensive Outdoor Recreation Plans (SCORP) which are available at present include:

1. 1975 Ohio Statewide Comprehensive Outdoor Recreation Plan (Ohio Dep. Nat. Resour. 1975),

2. Pennsylvania's Recreation Plan--1975 (Pa. Gov. Off. State Planning Dev. 1975), and

3. People, Resources, Recreation--New York Statewide Comprehensive Recreation Plan--1972 (N.Y. State Parks Rec. 1972).

Interaction between USLE gas development and production activities and SCORP policies from New York, Pennsylvania, and Ohio would occur primarily in considerations of land use. Any gas development program requires a number of onshore facilities for the development, production, and distribution of natural gas. Development of USLE gas would necessitate dock facilities, storage areas, and disposal sites for drilling wastes. The production phase of the program would require underwater collection pipelines and associated landfalls, compressor and gas processing facilities, and land-based distribution connections to existing pipelines. All land-based pipelines and facilities would require acquisition of pipeline easements.

Siting constraints for onshore facilities may result from SCORP policies of the three states. For example, policy statements from New York, Pennsylvania, and Ohio reflect a need to maintain an environment that is unspoiled for use by future generations. To achieve that goal, the SCORPs address the need for preserving areas considered to be of particular significance, in terms of their recreational, natural, scenic, or aesthetic value. A variety of agencies

are presently engaged in identifying significant areas that include wetlands, estuaries, unique natural features, bays, historic sites, and beaches. Foremost among these efforts is the designation of Geographic Areas of Particular Concern (GAPC) through the states' Coastal Zone Management programs. Other efforts include the U.S. Fish and Wildlife Service National Inventory of Wetlands and the Ohio Department of Natural Resources Natural Heritage Program.

Areas other than "significant areas" may also be removed from the landbank of available onshore facility sites as a result of the implementation of SCORP policies. These would include existing recreation facilities and possibly surrounding areas. For example, Pennsylvania Commonwealth policy is "*to acquire or assist other levels of government in their acquisition of . . . those areas which are needed to protect existing public recreation resources from encroachment*" (Pa. Gov. Off. State Planning Dev. 1975).

Furthermore, as stated in SCORP policies, the quality of existing facilities may be regulated and controlled through land-use controls created and legislated by local communities. The SCORPs of all three states promote policies that would encourage local governments to utilize relevant land-use controls to protect and enhance recreation resources. These controls include (1) construction zoning, (2) mandatory dedication, (3) acquisition of development rights and conservation easements, and (4) obtainment of right of first refusal.

Water quality is another fac r involved in a gas development program that would be subject tc SCORP policies. All three states recognize the importance of water quality for recreational pursuits. Their positions can best be summarized by New York's policy statement:

> "*Water is frequently an important part of outdoor recreation experiences, often it is a key element. Therefore, water quality and access to water must continue as a primary state concern*" (N.Y. State Parks Rec. 1972).

The potential for water quality degradation resulting from USLE natural gas development is directly related to disposal of drilling wastes, fracturing fluids, and brines, and to the potential for accidents involving the rig, support vessels, land disposal sites, or other components of the gas development program.

Another area involving SCORP policies in relation to USLE gas development and production is that of pipeline easements. In this instance, however, recreation planning in the three states can benefit from the opportunities afforded by the location of the gas program's pipelines and associated rights-of-way. These pipeline easements offer linear recreationways, providing the links in a recreation network for development as trails or bicycle paths. The three states share policy statements regarding the use of utility company resources for public recreation:

New York

"Use of existing transportation and utility corridors to extend the trail network will be given high priority as part of the implementation of a comprehensive recreationway and open space system. Where needs exist, trails, walkways, and bikeways should be developed as a component of roadway and utility corridor construction" (N.Y. State Parks Rec. 1972).

Ohio

"Existing corridors located along various rights-of-way provide excellent opportunities for establishing trails and can play a vital role in meeting present day and future trail needs (Ohio Dep. Nat. Resour. 1975).

Pennsylvania

"It is Commonwealth policy to encourage utility companies, which own or create resources of potential recreational value, to make these resources available to the public for appropriate recreation use" (Pa. Gov. Off. State Planning Dev. 1975).

COASTAL ZONE PLANNING

The Coastal Zone Management Act was enacted into law by the 92nd Congress on 27 October 1972; the act establishes a "national policy and develop[s] a national program for the management, beneficial use, protection, and development of the land and water resources of the Nation's coastal zones" [Coastal Zone Management Act of 1972 (Pub. L. 92-583) as amended by the Coastal Zone Management Act Amendments of 1976 (Publ. L. 94-370); hereinafter cited as the Coastal Zone Act]. Included in the definition of coastal zone are the waters and adjoining shorelands of the U.S. Great Lakes which have a "direct and significant impact on those coastal waters," (Coastal Zone Act § 304). Ultimate responsibility for implemention of the act is assigned to the secretary of commerce, although federal management authority has been delegated to the National Oceanic and Atmospheric Administration (NOAA). NOAA involvement is aimed at encouraging states to develop and implement individual management programs to ensure the preservation, development, and restoration of coastal zone resources. Two thirds of the cost for planning and implementation is provided by the federal government. The remaining one third must be financed by the state. Each state eligible to participate in the Coastal Zone Management (CZM) program must designate a lead agency responsible for developing a management plan. Once approved at the state and federal level, these management plans will serve as policy guidelines for coastal zone activities. To ensure maximum federal consistency, the act requires that federal licenses and permits for activities affecting land and water uses in the coastal zone may be granted only if the state certifies that the activity complies with its management program. State plans are, however, prohibited from arbitrarily excluding activities with desirable national impacts (Table 27). Moreover, the secretary of commerce may override a state's finding of inconsistency if it is determined that the proposed project is consistent with the

Table 27. Facilities in Which There May Be a National Interest in Planning or Siting[a]

Uses	Associated Facilities	Associated Federal Agencies
National defense and aerospace.	Military bases and installations; defense manufacturing facilities; aerospace facilities.	Department of Defense, National Aeronautics and Space Administration.
Energy production and transmission.	Oil and gas rigs, storage, distribution and transmission facilities; power plants; deep-water ports; LNG facilities; geothermal facilities; coal mining facilities.	Department of Energy, Department of Interior, Department of Commerce, Department of Transportation, Corps of Engineers.
Recreation.	National seashores, parks, forests; large and outstanding beaches and recreational waterfronts.	Department of Interior, Department of Agriculture.
Transportation.	Interstate highways; railroads; airports; ports; aids to navigation, including Coast Guard stations.	Department of Transportation, Department of Commerce, Corps of Engineers.
Regional water treatment plants.	Sewage treatment plants; desalinisation plants.	Environmental Protection Agency, Department of the Interior.

[a]From National Oceanic and Atmospheric Coastal Zone Management Program *Approval Regulations* (15 CFR 923; 43 FR 8395, 1 March 1978, effective 1 April 1978), 1978, Environmental Reporter 111:1680.

purposes of the act or "otherwise necessary in the interest of national security" [Coastal Zone Act § 307(3)(c)].

Before state management plans are approved at the federal level, lead agencies must provide NOAA with certain types of baseline information. For example, the backshore boundary of the coastal zone area must be defined. Also, the states have to develop and submit an objective approach for prioritizing the kinds of coastal zone activities that will be permitted. Additionally, the states are required to inventory and designate coastal "areas of particular concern" that demonstrate characteristics worthy of special consideration for preservation, restoration, or development. Finally, the states will have to provide evidence of their capabilities for working with federal, regional, and local governments and the public in both the planning and implementation phases of the program (Coastal Zone Act § 305).

Ohio, Pennsylvania, and New York CZM staffs are currently finalizing their plans prior to submission for NOAA approval. The Ohio CZM Program is presently organized as a section within the Division of Water, Department of Natural Resources; the program is focused on the promulgation of policies and management techniques to preserve, develop, or restore coastal resources (Ohio Dep. Nat. Resour. 1978). The policies and management techniques are centered around the following topical areas: flood and erosion hazard areas, air and water quality, areas of cultural significance, economic development, recreation and public access to the coastal zone, environmentally sensitive areas, general development and public investment, public involvement, and governmental coordination. As outlined in its program policies, the Ohio CZM

Program recognizes the need for offshore mineral resources development as long as navigation, fisheries habitats, and recreation are not adversely affected. Additionally, the Ohio program supports such policies as:

1. Continued bans on oil extraction from Ohio waters of Lake Erie,

2. Controlled test exploration for natural gas reserves in the central basin of Lake Erie to determine recoverable reserves, feasibility of extraction, and environmental impacts involved, and

3. Continued ban on natural gas exploration and extraction in the western basin.

Public review of the draft management plan is scheduled for December 1978. The plan must be reviewed and approved by the governor before it is released to NOAA.

Within the Commonwealth of Pennsylvania, the Department of Environmental Resources (DER) has been designated as the lead agency for development of the CZM plan. The program is being administered through the Division of Outdoor Recreation. Pennsylvania's coastal management plan is currently being revised to accommodate recommendations made by NOAA upon initial review (Fogg 1978--personal communication). In lieu of reviewing the currently unavailable management plan document, conversations with Coastal Zone Program Coordinator George Fogg, have clarified Pennsylvania's concern for Lake Erie area problems. Mr. Fogg has stated that policies and management techniques will address the following topical areas for Lake Erie: public access to shoreland areas, bluff erosion, coastal flooding, economic revitalization of Port Erie, and gas development in Lake Erie. Mr. Fogg emphasized that recommendations published in a report sponsored by the Pennsylvania DER (Krais and Oostdam 1976) are reflective of the official CZM program position concerning Lake Erie gas development:

> *Although insufficient information exists to permit oil exploration on Lake Erie, there is little reason not to explore natural gas as an offshore resource provided that the exploration be well regulated.*
>
> *PDER should establish an updated program of development and enforcement of regulations concerning offshore operations. These regulations must insure that toxic substances be tested for permitted use, that recreational and water resources will not be interfered with in any unreasonable way, and that an extensive program of inspection and surveillance be established. Additionally, operation should conform to existing water quality standards in effect on the Lake as regards disposal of any wastes generated by the crew or through drilling operations.*

New York's CZM program is presently being administered through the New York Department of State. Due to New York's shoreline contact with the Great Lakes, the St. Lawrence Seaway, and Atlantic Ocean waters, the state has been divided into five management regions: (1) Great Lakes West, (2) Eastern Ontario-St. Lawrence River, (3) Hudson River, (4) New York City area, and

(5) Long Island. Responsibility for planning and implementation activities for the New York Lake Erie Coastal Zone has been delegated to the Great Lakes West group.

In a summary of New York's coastal zone planning objectives (N. Y. Dep. State 1978), the CZM staff has listed the following issues or concerns that will serve as the foundation for development of the coastal management plan: aesthetic resources; recreation resources; public access to shorelands; economic development; impacts of outer continental shelf activities; energy facilities and resources; agricultural resources; coastal flooding and erosion; fish, wildlife and their habitats; coastal water resources; and coastal air resources. Policies and management techniques included in the management plan will address these topical areas. The coastal management staff cautioned that "*Lake Erie gas development should be explored in an environmentally compatible manner.*" The report also pointed out that an environmental impact statement will be required under the State Environmental Quality Review Act for all new energy facilities needing state of local permits.

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INSTITUTIONAL ISSUES

DEVELOPING AND IMPLEMENTING A REGULATORY PROGRAM

Developing and implementing a regulatory program for new industrial activity is often a complex and difficult task. Given the potential for environmental damage in the development of USLE natural gas resources, a strong, effective program is a necessity. Yet care must be taken to ensure that the sheer weight of the program does not prove to be an unreasonable impediment to the activity. Overlapping and unneccessary regulations, at both the state and federal levels, should be avoided.

One way in which efficiency might be increased is through the development of standardized state regulatory programs. Common elements which might be treated alike include leasing terms, water quality requirements, waste disposal, accident response procedures, and inspection provisions. At present, each of the states has been proceeding independently. Discussions between representatives of the states' oil and gas programs concerning Lake Erie gas have led to little progress (Ohio Dep. Nat. Resour. 1978--personal communication). Although the states do belong to some of the same regional commissions (e.g., Great Lakes Basin Commission), these organizations do not provide adequate mechanisms for developing common programs or for settling the disputes that may arise. Potential areas for conflict include simultaneous reservoir development, accidentally discharged pollutants, and lease tract boundaries. These same issues may arise between the states and Ontario.

A third problem in implementing a regulatory program is the administrative costs that would be involved. Representatives from each of the three states have expressed concern over the availability of sufficient funding. One way to meet this problem is through interagency cooperation. It has been suggested that the states' oil and gas inspectors might also enforce environmental regulations (Ohio EPA 1978--personal communication). Another option would be to draw the program's funds directly from the rental fees or royalties paid by the gas operators. Whatever method is used, this issue must be met before the public can be assured of adequate environmental protection.

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TECHNOLOGICAL OVERVIEW--NORMAL OPERATIONS

SITING THE WELL

The well is sited in the same manner in all instances, thus the following description is applicable to all four drilling programs mentioned. Usually, company geologists employ all known information concerning subsurface geology with respect to well-site selection. In addition to subsurface geological information, seismic data are often required. These data are obtained using a seismically instrumented ship that generates sound wave impulses in the lake water using air gun devices. Unlike dynamite, these devices do not harm fish when used to generate seismic impulses (Lawler, Matusky & Skelly 1977). The generated shock waves travel down through the earth's crust and are reflected back to the surface where receivers record the seismic wave travel time. This information is used to produce geophysical structure maps showing potential gas-bearing structures beneath the Lake.

Once geologists pinpoint a potential gas-bearing formation, surveyors are contracted to locate the desired area in the Lake. A buoy is dropped at the exact location, marking it for the drilling rig. A rig is floated to a location and, once in correct position, is secured either by bottom contact (jack-up rig) or with an anchoring system (drilling ship).

Generalized shallow-well (Silurian) drilling operations for jack-up rig drilling and floating drilling are given in Table 28. Similar operations are presented for deep-well (Cambrian) drilling in Table 29.

DRILLING

Drilling conditions in USLE will be similar to those experienced in Canadian waters. The major difference will be the increased thickness of lake bottom sediments and underlying shale on the U.S. side, which will necessitate drilling deeper before encountering competent bedrock such as the Onondaga limestone. This geological condition alone may rule out what has been called "open-cycle drilling." This term means that the drilling fluid and cuttings travel from the wellbore to the lake floor without coming back up to rig level. In open-cycle drilling the wellbore is exposed to the Lake itself and there is no steel casing (pipe) to transport cuttings, gases, or fluids back to the rig floor level. Use of this drilling technology also means that there is absolutely no way of controlling the well should high pressure gas or oil be encountered. Since high pressure gas pockets do exist (see p. 35) in the shale layer resting on top of the Onondaga limestone, open-cycle drilling should probably not be permitted in Lake Erie if gas development is allowed.

Table 28. Shallow-Well Drilling for Silurian Test

Floating Drilling	Jack-up Rig Drilling
1. Move and anchor rig over surveyed location. Drill 14-3/4 in.-diameter hole approximately 30 ft into bedrock. Displace surface hole with mud as required and trip out with drill string.	1. Move and jack up drilling platform over surveyed location and drill 11 in.-diameter surface hole. Drill surface hole a minimum of 50 ft into competent bedrock. If a large amount of surface gas is encountered, notify the drilling office. It will then be decided if a D.V. cementing collar and packer should be run on the 8-5/8 in. casing. Circulate hole to surface with mud.
2. Run 9-5/8 in. O.D.[a] K-55 36 lb/ft, Range 2, short threaded and coupled casing. Bottom collar is to be saw-toothed. Install 9-5/8 in. casing bowl and run to lake bottom on 5.0 in. collars. The 9-5/8 in. casing is to be set on the bottom of the hole. Have diver check and report the location of casing bowl. The casing bowl is to be set at or below Lake bottom. Casing is to be lowered to this position with drill collars running back to rig floor.	2. Run 8-5/8 in. O.D.[a] K-55, 24 lb/ft, Range 2, short threaded and coupled casing, complete with float shoe, baffle collar, centralizer, and limit clamp on bottom. Weld float shoe, baffle collar, and first joint. Install one combination cement basket and centralizer between the fourth and fifth joints. Install centralizers every fifth joint above cement basket. Install an 8-5/8 in. × 10-3/4 in. casing head body and run 10-3/4 in. conductor pipe to rig floor.[f]
3. Mix and displace approximately 100 sacks of an appropriate cement, slurry weight 14.7 lb/gal with 3% $CaCl_2$ to within 30 ft of the bottom of 9-5/8 in. casing string. Use water as displacing fluid. Allow cement level to equalize.	3. Cement the casing using an 8-5/8 in. × 10-3/4 in. combination top wiper plug with an appropriate cement at 14.7 lb/gal and 3% $CaCl_2$. No other additives are to be used. Collect cement samples for inspection; a pressure recorder is to be used. A scuba diver must be on hand to make two dives: first to check the wellhead before cementing to ensure it is positioned at or below lake bottom and second to check on cement returns and to clear cement away from the landing string. Diving logs must be completed by the diver and signed by the toolpusher.
4. Have diver go down to unbolt landing flange from 9-5/8 in. casing bowl. Pull drill collars back out of Lake.	4. Install 10-3/4 in. conductor clamp below 10-3/4 in. union on landing joint. Back off cement-head landing joint after six hours.
5. Make up stinger of 3-1/2 in. drill pipe with landing sub and have diver go down to stab into 9-5/8 in. casing bowl.	5. Rig up BOP[b] while WOC[c]. Test BOP[b] to 800-1000 psig just prior to drilling out shoe.
6. Run blowout preventers, conductor barrel (marine riser), and slip-joint assembly over stinger; set into place on 9-5/8 in. casing bowl. Have diver make up Cameron swing bolt clamp.	6. Drill out 11 in. hole after 8 hours WOC[c]. Pressure test formation with one pump to establish rupture pressure. Do not exceed 150 psig. If breakdown occurs, record pressure and post. The 8-5/8 in. casing must be recemented if pressure cannot be held.
7. Install 10-3/4 in. Grant rotating head on top of slip-joint assembly.	7. Drill 6-3/4 in. hole to 100 ft above Guelph formation. Install rotating head and drill to T.D.[d]
8. Pressure test BOP[b] and clamp to 100 psi prior to drilling out cement in 9-5/8 in. casing.	8. Run D.S.T.[e] as requested by wellsite geologist.
9. After 8 hours WOC,[c] drill out cement shoe and drill 3-3/4 in.-diameter hole to casing point as stated in prognosis.	9. Company representative will instruct as to requirements for drilling overhole.
10. Run 7 in. O.D.,[a] K-55 20 lb/ft, Range 2, short threaded and coupled casing complete with float shoe, baffle collar, centralizer, and limit clamp on bottom. Weld float shoe, baffle collar and first joint. Install one combination cement basket and centralizer on the third joint and centralizers on every fifth joint above the cement basket. Install a second combination of cement basket and centralizer above water zone. Install 7 in. casing hanger and run 7 in. conductor pipes to rig floor. Have diver lock 7 in. casing hanger in 9-5/8 in. casing bowl.	10. Log as requested by wellsite geologist.

Table 28. (Continued)

Floating Drilling	Jack-up Rig Drilling
11. Cement casing into place using a 7 in. top wiper plug with appropriate cement at 14.7 lb/gal and 2% $CaCl_2$. Use no other additives. Collect cement samples for inspection; a pressure recorder is to be used. Circulate 10-3/4 in. conductor barrel clean using kill lines and check for cement returns at surface. Keep 7 in. casing shut-in at surface for two to four hours if float does not hold.	11. Company representative to instruct as to completion or abandonment of hole.
12. Back off and lay down 7 in. landing string. Run in with 6-1/4 in. bit. After 8 hours WOC,[c] pressure test BOP[b] and casing to 1000 psig.	
13. Drill out 8-3/4 in. hole after 8 hours WOC[c]. Pressure test formation with Triplex pump to establish the rupture pressure. Do not exceed 100-150 psig. If breakdown occurs, the pressure should be recorded and posted. The 7 in. casing must be re-cemented if pressure cannot be held.	
14. a. Drill 6-1/4 in. hole to Guelph formation, or its equivalent. Circulate hole with a polybrine drilling mud. Drill to T.D.[d]	
b. Coring may be done at discretion of company representative. Mud up with polybrine at core point. Trip for core barrel and run in with same. Core using full-hole core bit. Use mud to overbalance formation by 100-150 psi.	
15. Run D.S.T.[e] as requested by wellsite geologist.	
16. Company representative will instruct as to requirements for drilling overhole.	
17. Log as requested by wellsite geologist.	
18. The company representative will instruct as to completion or abandonment of hole.	

[a] O.D. = outside diameter.

[b] BOP = blowout preventer.

[c] WOC = waiting on cement.

[d] T.D. = total depth.

[e] D.S.T. = drillstem test.

[f] In the event of tight-hole problems, toolpusher will use his discretion on using centralizers on that hole to avoid creating further problems when running 8-5/8 in. casing.

Measurements and conversions: Nominal measurements employed in this description refer to the shelf descriptions of items, not to dimensions; in such cases metric conversions would be inappropriate.

- Metric conversion factors:
  1. in. to cm, multiply by 2.540.
  2. ft to m, multiply by 0.3048.
  3. lb/gal to kg/m^3, multiply by 99.77633.
  4. psi to kPa, multiply by 6.895.

Table 29. Deep-Well Drilling for Cambrian Test

Floating Drilling	Jack-up Rig Drilling
1. Move and anchor rig over surveyed location. Drill 17-1/2 in.-diameter hole approximately 50 ft into bedrock. Displace hole to surface with mud as required and trip out with drill string.	1. Move and jack up drilling platform over surveyed location and drill 11 in.-diameter surface hole. Drill surface hole a minimum of 50 ft into competent bedrock (found at approximately 400 ft). If a large amount of surface gas is encountered, notify the drilling office. Circulate hole to surface with mud. Trip out drill pipe.
2. Run 13-3/8 in. O.D.,[a] H40, 48 lb/ft, Range 2, short threaded and coupled casing. Bottom joint to be saw-toothed. Install 13-3/8 in. flange on casing. Rig up 5.0 in. collars with 9-5/8 in. × 13-3/8 in. change-over, and a 13-3/8 in. flange. Run 13-3/8 in. casing to lake bottom on 5.0 in. collars. A scuba diver to confirm that 13-3/8 in. casing bowl is 1 in. below lake bottom.	2. Run 9-5/8 in. O.D.,[a] K-55, 36 lb/ft, Range 2, short threaded and coupled casing, complete with float shoe, baffle collar, centralizer, and limit clamp on bottom. Preweld float shoe, baffle collar, and first joint on pipe rack. The second joint will be secured to the baffle collar using the appropriate cement. Install one combination cement basket and centralizer between the fourth and fifth joints. Install centralizers every fifth joint above cement basket. Install a 9-5/8 in. × 13-3/8 in. casing head body and run 10-3/4 in. conductor pipe to rig floor. Bottom joint of 10-3/4 in. casing to have 2 in. thread-O-let welded on and a 2 in. side valve with union installed for circulating cement from conductor barrel.[1]
3. Mix and displace approximately 150 sacks of appropriate cement with 3% $CaCl_2$. Cement weight to be 14.7 lb/gal. Displace cement with water and allow cement to equalize.	3. Cement the casing using a 9-5/8 in. × 10-3/4 in. combination top wiper plug with an appropriate cement at 14.7 lb/gal and 3% $CaCl_2$. No other additives are to be used. Collect cement samples for inspection; a pressure recorder is to be used. The diver must be on hand to make two dives: first to check the wellhead before cementing to ensure it is positioned at or below lake bottom and second to check on cement returns and to clear cement away from the landing string. Diving logs must be completed by the diver and signed by the toolpusher.
4. Have diver go down and unbolt 13-3/8 in. landing flange and trip out 5.0 in. collars.	4. Install 10-3/4 in. conductor clamp below 10-3/4 in. union on landing joint. Back off cement head landing joint after 6 hours.
5. Rig up and trip in 12-1/4 in. bit and 7 in. collars. Strip 9-5/8 in. × 13-3/8 in. change bowl over collars and let it sit on 12-1/4 in. bit. Have diver stab 12-1/4 in. bit into 13-3/8 in. casing bowl. Support collars at rig floor and have diver make up 13-3/8 in. × 9-5/8 in. change-over.	5. Rig up blowout preventer while waiting on cement. Test BOP[c] to 800-1000 psig just prior to drilling out above the baffle collar and shoe.
6. Trip in 7 in. collars and 12-1/4 in. bit and install 3-1/2 in. stinger of drill pipe with landing sub. Land in 9-5/8 in. casting bowl.[b]	6. Drill out hole after 8 hours WOC[e]. Pressure test formation with one pump to establish rupture pressure. Do not exceed 150 psig. If breakdown occurs, record pressure and post. The 9-5/8 in. casing must be recemented if pressure cannot be held.
7. Run BOP,[c] conductor barrel, and slip-joint assembly over stinger and set into place on 9-5/8 in. casing bowl. Have diver make up Cameron swing bolt clamp.	7. Take deviation surveys throughout drilling of 8-3/4 in. hole.
8. Install 10-3/4 in. Grant rotating head on top of slip-joint assembly complete with oversized Grant head rubber.	
9. Pressure test BOP[c] and clamp to 250 psi prior to drilling and cement in 13-3/8 in. casing.	
10. After 8 hours drill out 13-3/8 in. casing with a 12-1/4 in. bit. Drill 12-1/4 in. hole to approximately 950 ft to confirm that surface gas is not present. (Actual depth to be stated in prognosis.)	

Table 29. (Continued)

Floating Drilling	Jack-up Rig Drilling
11. If there is no surface gas, displace hole to surface with mud and trip out drill pipe and collars to the point where landing sub was installed. Install landing sub on 7 in. collars and set in 9-5/8 in. casing bowl.[d]	8. Drill 8-3/4 in. hole to 100 ft above Guelph formation, or its equivalent. Install rotating head and drill into the Queenston, or its equivalent.
12. Have diver unbolt 13-3/8 in. flange and trip out BOPs.[c]	9. Log as requested by wellsite geologist.
13. Trip out 7 in. collars and 12-1/4 in. B.T.	10. Run D.S.T.[g] as requested by wellsite geologist.
14. Run 9-5/8 in. O.D.,[a] K-55, 36 lb/ft, Range 2, short threaded and coupled casing, complete with 9-5/8 in. guide shoe and 9-5/8 in. baffle collar. Run a centralizer on bottom, a combination cement basket and centralizer on joint number 4, a centralizer on joint number 7, and a combination cement basket and centralizer on joint number 10 (inside 13-3/8 in. casing). Install a 9-5/8 in. casing bowl and land in 13-3/8 in. casing bowl. Diver to stab in casing. Run 9-5/8 in. casing to rig floor.	11. <u>7 in. Casing Program</u>: Run 7 in. O.D.,[a] K-55, 20 lb/ft, Range 2, short threaded and coupled casing complete with float shoe, baffle collar, centralizer, and limit clamp on bottom. Preweld float shoe, baffle collar, and first joint on pipe rack. An appropriate cement will be used to bond number 2 joint and baffle collar. Install one combination cement basket and centralizer on the third joint and centralize every fifth joint above cement basket. Install second cement basket 40 ft above Guelph (or equivalent) formation, a third above Oriskany formation, and a fourth in the bottom of the 9-5/8 in. casing. Install 7 in. casing hanger and run 7 in. conductor pipes to rig floor. Have diver lock 7 in. casing hanger in 9-5/8 in. casing bowl and chain down 7 in. casing at rig floor for cementing. Run 2-3/8 in. line complete with 2 in. valve on top and swing joint on bottom. Have diver hook up same and open 2 in. valve on conductor barrel. Make one complete circuit with mud prior to cementing. Pump ten barrels of fresh water and cement 7 in. casing with a 6% gel cement, slurry weight 13.4 lb/gal. Follow gel cement with a fifty-sack tail-in of an appropriate cement with 2% $CaCl_2$ at 14.7 lb/gal. Collect cement samples for visual inspection. Displace top plug with water. Bleed off pressure at cement head and check for flowback. If no flowback, break out 7 in. landing string and circulate cement from conductor barrel. Trip out landing string. If flowback occurs, 7 in. casing should be left shut-in for 4 hours. Circulate 10-3/4 in. conductor barrel clean through 2-3/8 in. line tied into bottom of conductor barrel. Back off. Trip out 7 in. landing string after 4 hours WOC.[e] Run in with 6-1/4 in. bit. After 10 hours WOC,[e] pressure test BOP[c] and casing from top of the baffle collar to surface to 1000 psig.
15. Rig up and cement with an appropriate cement, slurry weight 14.7 lb/gal. Displace cement with 9-5/8 in. top wiper plug.	
16. Have diver go down and break out landing flange from 9-5/8 in. casing bowl. Trip out 9-5/8 in. landing string.	
17. Make up stinger of 3-1/2 in. drill pipe with landing sub and have diver stab into 9-5/8 in. casing bowl.	
18. Run BOP,[c] conductor barrel, and slip-joint assembly over stinger and set into place on 9-5/8 in. casing bowl. Have diver make up Cameron swing bolt clamp.	
19. Install 10-3/4 in. Grant rotating head on top of slip-joint assembly.	
20. After 8 hours, pressure test BOP[c] and clamp to 100 psig prior to drilling out 9-5/8 in. baffle collar and cement.	12. Drill out baffle collar and 7 in. casing with 6-1/4 in. bit after 10 hours WOC.[e] Pressure test formation with Triplex pump to 500 psig.
21. Drill out 9-5/8 in. baffle collar and shoe with an 8-3/4 in. bit. After 8 hours WOC,[e] pressure test formation and cement job with Triplex pump to establish rupture pressure. Do not exceed 100-150 psig. If breakdown occurs, the pressure should be recorded and posted. The 9-5/8 in. casing must be recemented if pressure cannot be held.	13. Take deviation surveys throughout drilling of 6-1/4 in. hole.

Table 29. (Continued)

Floating Drilling	Jack-up Rig Drilling
22. Take deviation surveys throughout drilling of 8-3/4 in. hole.	14. a. Drill 6-1/4 in. hole to T.D.[h] with water. If conditions dictate, mud could be used for drilling.
23. Drill 8-3/4 in. hole to the Guelph formation, or its equivalent. Circulate hole with polybrine mud. Drill into Queenston, or its equivalent.	b. Coring may be done at discretion of company representative. Mud up with fresh water mud at core point. Trip for core barrel and run in with same. Core using full-hole core bit. Use mud to overbalance formation by 100-150 psi.
24. Coring may be done at discretion of company representative. Mud up at core point. Trip for core barrel and run in with same. Core using full-hole core bit. Use mud to overbalance formation pressure by 100-150 psi.	15. Log hole as requested by wellsite geologist.
25. Log as requested by wellsite geologist.[f]	16. Run D.S.T.[g] as requested by wellsite geologist.
26. Run D.S.T.[g] as requested by wellsite geologist.	17. The company representative is to instruct as to completion or abandonment of hole.
27. 7 in. Casing Program: Run 7 in. O.D.,[a] K-55, 20 lb/ft, Range 2, short threaded and coupled casing complete with float shoe, baffle collar, centralizer, and limit clamp on bottom. Preweld float shoe, baffle collar, and first joint on pipe rack. An appropriate cement will be used on bond number 2 joint and baffle collar. Install one combination cement basket and centralizer on the third joint and centralize every fifth joint above cement basket. Install second cement basket 40 ft above Guelph formation, a third above Oriskany formation, and a fourth in the bottom of the 9-5/8 in. casing. Install 7 in. casing hanger and run 7 in. conductor pipes to rig floor. Have diver lock 7 in. casing hanger in 9-5/8 in. casing bowl. Make one complete circulation with mud prior to cementing. Pump ten barrels of fresh water and cement 7 in. casing with a 6% gel cement, slurry weight 13.4 lb/gal. Follow gel cement with a fifty-sack tail-in of an appropriate cement with 2% $CaCl_2$ at 14.7 lb/gal. Displace top plug with water. Bleed off pressure at cement head and check for flowback. If no flowback, break out 7 in. landing string and circulate cement from conductor barrel. Trip out and lay down 7 in. landing string. If flowback occurs, 7 in. casing should be left shut-in for 4 hours and conductor barrel circulated out using kill line.	
28. Run in with 6-1/4 in. bit. After 10 hours WOC,[e] pressure test BOP[c] and casing from top of the baffle collar to surface to 1500 psig.	

Table 29. (Continued)

Floating Drilling	Jack-up Rig Drilling
29. Drill out baffle collar and 7 in. casing with 6-1/4 in. bit after 10 hours WOC.[e] Pressure test formation with Triplex pump to 500 psig. The 7 in. casing must be recemented if pressure cannot be held.	
30. Take deviation surveys throughout drilling of 6-1/4 in. hole.	
31. a. Drill 6-1/4 in. hole to T.D.[h] with mud.	
b. Coring may be done at discretion of company representative. Mud up with freshwater mud at core point. Trip for core barrel and run in with same. Core using full-hole core bit. Use mud to overbalance formation by 100-150 psi.	
32. Log hole as requested by wellsite geologist.	
33. Run D.S.T.[g] as requested by wellsite geologist.	
34. The company representative to instruct as to completion or abandonment of hole.	

[a]O.D. = outside diameter.

[b]1. Run sufficient 7 in. collars to allow for pulling up stinger and removal of landing sub.

2. It might be necessary to drill out cement prior to installing landing sub for sufficient depth (to within 10 ft).

[c]BOP = blowout preventer.

[d]If surface gas is encountered, a decision will have to be made to either plug the hole or wait until the surface gas stops flowing.

[e]WOC = waiting on cement.

[f]Refer to prognosis for test instruction prior to drilling to Queenston.

[g]D.S.T. = drillstem test.

[h]T.D. = total depth.

[i]The 9-5/8 in. casing head bowl used with the floater has been altered by machining a left-hand ACME thread to accommodate 10-3/4 in. conductor pipe.

In the event of tight-hole problems, the toolpusher will use his discretion on whether to use centralizers on that hole to avoid creating further problems when running 9-5/8 in. casing.

Measurement and conversions: Nominal measurements employed in this description refer to the shelf description of items, not to dimensions, in such cases metric conversions would be inappropriate.

Metric conversion factors:
1. in. to cm, multiply by 2.540.
2. ft to m, multiply by 0.3048.
3. lb/gal to kg/m^3, multiply by 99.77633.
4. psi to kPa, multiply by 6.895.

The alternative to open-cycle drilling is "closed-cycle drilling." This means that the drilling fluid is in an essentially closed circuit:* the mud pump circulates drilling fluid from the suction mud tank and discharges this mud into the rotary hose connected to the swivel (coupling connecting mud pump and drill string; permits latter to rotate) that screws onto the kelly (slotted square or hexagonal, hollow steel pipe that couples to the topmost joint of the drill pipe). The kelly screws into the drill string (drill pipe with tool joints attached) at the bottom of which is the bit (cutting element used to cut through rock). Drilling mud flows from the pump down the drill string, through the bit, and back up the annulus (space between drill pipe and bore wall or between pipe and steel casing) to the surface (rig floor). At rig floor level the cuttings are removed via a shale shaker (vibration screen; removes rock cuttings before mud is returned to mud tank) and the fluid winds its way back to the suction tank, its point of origin (Fig. 10).

Required drilling muds are a potential source of freshwater pollution during the drilling of wells in Lake Erie. However, it must be pointed out that drilling muds used to date are chemically *very simple*. Standard mud programs in use today in the Canadian waters of Lake Erie are presented in Table 30. The more common components of these drilling mud systems are generally described in Table 31.

Initial closed-cycle drilling through unconsolidated sediments (spudding in) is usually accomplished by driving a conductor or structural casing (string of large-diameter steel pipe used to secure the hole, prevent wall collapse, and provide means for conveying drilling fluids to surface) with a pile driving hammer into the lake floor to refusal (Table 29). Then blowout preventer (BOP) equipment is installed on this casing to be used with diverter equipment in case high pressure gas is encountered while drilling the surface hole. The initial hole is closed-cycle drilled through this drive pipe.

These three steps provide two distinct advantages. Nothing is discharged** into the Lake and well control is excellent. If high pressure gas is encountered, it is allowed to flow through the diverter system and is released with less danger of fire, pollution of water, and/or loss of the rig and personnel.

Pressures encountered while drilling and producing on the U.S. side of the Lake (assuming drilling is allowed) will undoubtedly be low compared to the working pressure rating of BOP equipment. Such equipment is available with 21,000; 34,000; 69,000; 100,000; and 140,000 kPa (3,000; 5,000; 10,000; 15,000; and 20,000 psi) ratings. To illustrate the magnitude of the pressures to be encountered in Lake Erie drilling, one can look at a worst-case situation. Suppose a well is to be drilled to a maximum depth of 1372 m (4500 ft). The highest pressure gradient encountered to date is about 11.8 kPa/m (0.52 psi/ft) of depth. Therefore the maximum bottom hole pressure that one would expect to encounter is 11.8 kPa/m × 1372 m = 16,190 kPa (2348 psi). Subtracting 1.8 kPa/m (0.08 psi/ft) to compensate for the gas column gradient,

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*Minor losses of drilling fluids may result from spillage on the rig floor when new lengths of drill pipe are added or removed from the drill string. In addition, small losses occur from adsorption of fluids on drill cuttings.

**This assumes that rock cuttings are not returned to the Lake; spillage losses are essentially nil.

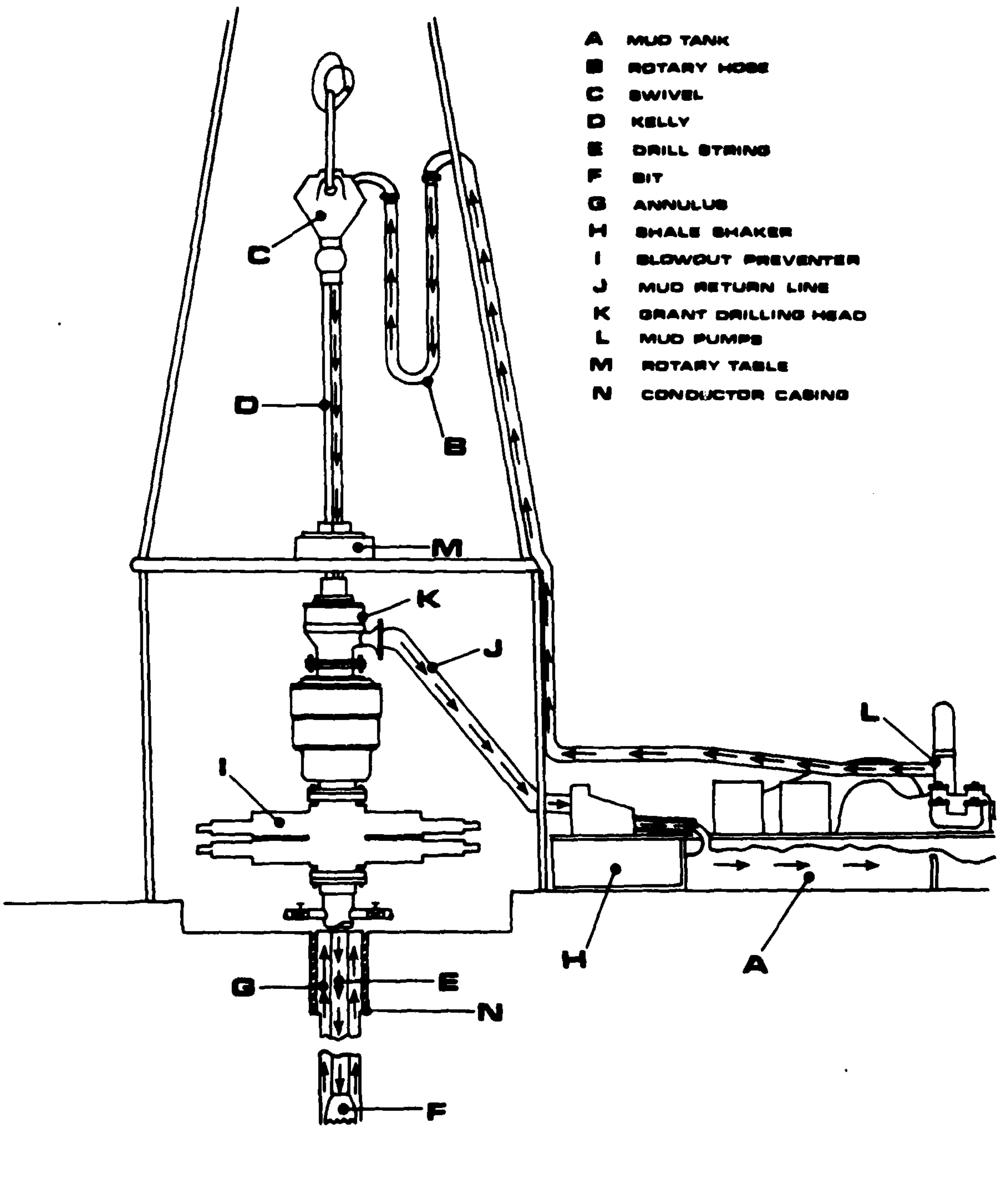

Figure 10. Schematic Diagram of Drilling Equipment, Identifying Essential Hardware and Drilling Mud Flow Pattern. Data from Hurd and Kingston (1978).

Table 30. Standard Mud Programs Used in Canadian Offshore Drilling in Lake Erie

Long-hole Polybrine Mud System (standard)	Weighted Freshwater Mud System (barite)
Properties	
35-40 sec viscosity	50-60 viscosity
12-16 cc fluid loss	4-6 cc fluid loss
1.22-1.26 kg/L (10.2-10.5 lb/gal)	9.5 -10 pH
10.0-10.5 pH	10.0 lb/gal
Components	
a. Water 160 L (36 gal Imperial, 43 gal U.S.)	a. Bentonite clay 9.1 kg (20 lb)/bbl
b. $CaCl_2$ 56 kg (124 lb) (98%)	b. Caustic 0.11-0.23 kg (0.25-0.50 lb)/bbl
c. Calcium carbonate and hydroxyethylcellulose (HEC) 1.4 kg (3 lb)/bbl	c. Chrome lignites 0.45 kg (1 lb)/bbl
d. Calcium carbonates, lignosulfonates HEC, lime, trivalent chrome salt 2.3 kg (5 lb)/bbl	d. Sodium carboxylmethylcellulose 0.11-0.23 kg (0.25-0.50 lb)/bbl
e. Calcium carbonates 2.3 kg (5 lb)/bbl	e. Barite 27.2 kg (60 lb)/bbl
Mixing Procedures	
1. Premix *b* in water to the desired weight 4.6 to 4.8 kg (10.2 to 10.5 lb)/gal.	1. Premix *a* with fresh water to prehydrate in advance of mixing *e*, *a* is added for viscosity and fluid loss at approximately one rack every four minutes.
2. Prior to adding *c*, *d*, or *e*, add 0.25 to 0.23 kg (0.50 lb)/bbl 2-ethylhexonol to the brine to minimize foaming.	2. Mix *e* as required for weight.
3. Mix *c*, *d*, and *e* through the hopper adding each at a slow rate. Circulate fluid through the hopper as rapidly as possible.	3. Add *c* very slowly to system for fluid loss control.
4. To increase weight and/or viscosity, $CaCl_2$ or *c* may be added directly to mud tanks and the solution agitated using the mud guns. This helps avoid the problem of foaming. During mixing of new mud, or when increasing the weight of existing system, the derrick operator must maintain continued checks on the drillings mud properties. These must be recorded on the tour sheet when mixing is complete. Mud must be checked and circulated in the tanks every 12 hours and the properties recorded in the tour sheets when not being used. Mud must be checked and the properties recorded every 2 hours when the mud is being used.*	

Surface hole mud = mix bentonite clay until a viscosity of 100 sec is obtained.

*If a salt zone is encountered in a well and there is no significant oil or gas show, a decision to drill deeper may be made. In this case, the drilling may continue using the $CaCl_2$-saturated brine solution as the drilling fluid. If oil or gas is encountered down hole, drilling will be continued with Polybrine.

Table 31. Common Components of Drilling Muds Used in Canadian Drilling Operations in Lake Erie

Component	Description	Primary Application
Bentonite clay	Viscosifier	Control of viscosity and filtration for waterbase muds
Barite	Weighting agent	Increase weight of drilling muds up to 0.08 kg/L (20 lb/gal)
Chromelignosulfonate	Dispersant	Dispersant and fluid loss control for waterbase muds
Carboxymethylcellulose	Fluid loss reducer	Controls fluid loss and weighting agent suspension in waterbase muds
Calcium carbonate and hydroxyethylcellulose	Weighting agent	Increase weight of drilling mud
Calcium chloride	Weighting agent	Increase weight of drilling mud
Calcium carbonates and lignosulfonates	Dispersant	Weighting, dispersant, and fluid loss agent
2-ethylhexonol	Defoamer	Defoamer for slightly salty muds treated with lignosulfonates

one can calculate a surface pressure (shut-in wellhead pressure) of 13,720 kPa (1990 psi). A drilling fluid with a density equal to 1.26 kg/L (10.5 lb/gal) will more than balance any known reservoir pressures.

Water depths in Lake Erie are such that several types of drilling vessels have the capability of drilling there. However, the most likely types will be in two broad classes: floating vessels and bottom-supported structures. Floating vessels include drillships and floating barges anchored onsite. Bottom-supported structures encompass jack-up rigs and submersible barge-type rigs.

Currently, and this will probably continue to be true in the future, two basic programs are used with floating vessels and two with jack-up rigs (Brooks--personal communication). In each case, the objective* of the well (Silurian or Cambrian) determines the general program to be employed.

*Objective refers to the formation in which hydrocarbons are anticipated.

GENERALIZED WELL COMPLETION PROCEDURE

Once a well is drilled according to one of the plans presented in Tables 28 and 29, and gas has been found, the well must be completed. This is done by making permanent contact between each productive geologic horizon and the wellbore. The appropriate equipment for controlling fluid or gas flow is installed. For a technical description of this procedure, see Table 32.

WELL STIMULATION

If a well is deemed commercially productive it is stimulated to increase gas flow. After wells are drilled, cased, cemented, and completed, they are left unattended and shut-in awaiting stimulation treatments and pipeline connections. Stimulation is required because the producing formations under the Lake are of low porosity and permeability and thus have a low production capacity. Two types of stimulation treatments have been used in the past: hydrochloric acid (HCl) treatments and water-based fluid--sand fracturing treatments.

Many wells are treated sequentially in the same general time period. This is accomplished by using a stimulation barge. The barge is large enough to carry the engines, pumps, and materials to sand fracture three wells. It also has the necessary tankage for hydrochloric acid.

The normal procedure for stimulating wells producing gas from the Guelph limestone formation involves slowly forcing approximately 1900 L (500 gal) of 15% HCl acid into the formation at a pressure of about 9700 kPa (1400 psig). Other formations usually require a fracturing treatment. For a typical fracturing treatment, the following materials are pumped into the producing formation from the barge:

1. 1900 L (500 gal) HCl
2. 95 m^3 (600 bbl) water
3. 17,200 kg (38,000 lb) sand
4. 95 L (25 gal) surfactant (chemical composition unknown)
5. 1130 kg (2500 lb) $CaCl_2$
6. 360 kg (800 lb) Gel (chemical composition unknown)
7. 5700 m^3 (200,000 SCF) CO_2

Venting Procedures

Pressurized liquids and gases are pumped from the barge to the wellhead through high-pressure steel lines. It may take more than 13,790 kPa (2000 psi) to fracture some tight sandstone formations. After all of the stimulation gas and/or liquid is forced into the gas-bearing formation, the well is shut-in for a period of from a half hour to several days, depending on specific formation characteristics. After the shut-in period the well is reopened to allow gases and/or liquids not lost to the formation to return from the well. These materials are piped back to the stimulation barge and separated into gas

Table 32. Well Completion Procedure

1. Plug back well from T.D.[a] to pay zone. Run drill pipe with plug back sub installed. Cement with an appropriate cement as required. Pull up drill pipe to desired plug back top and circulate clean with water.

2. Run in 4-1/2 in. casing to approximately 300 ft K.B.[b] Install 4-1/2 in. float show on bottom and one 4-1/2 in. × 7 in. combination cement basket and centralizer on the first joint. Centralize every second joint above cement basket. Install 4-1/2 in. casing hanger and land in wellhead. Rig to cement, chain down 4-1/2 in. casing.

3. Run in 2-3/8 in. E.U.E.[c] tubing to circulate conductor barrel after cementing.

4. Cement 4-1/2 in. casing with an appropriate cement at 14.7 lb/gal and 3% $CaCl_2$. Displace cement with water using a 4-1/2 in. top wiper plug.

5. Bleed off 4-1/2 in. casing to see if float is holding. Shut-in casing at cement head for 4 hours.

6. Circulate conductor barrel clean through 2-3/8 in. tubing.

7. After 4 hours, break off 4-1/2 in. landing string.

8. Make up 3-7/8 in. bit to 3-1/2 in. collars and trip in on 2-3/8 in. E.U.E.[c] tubing. Drill out plug, float shoe and cement after 8 hours WOC.[d]

9. Trip out drill string.

10. Rig up and run 2-3/8 in. E.U.E.[c] tubing and tag P.B.T.D. Let tubing set on bottom and pull BOP[e] and conductor barrel.

11. Pull up and spot 15% HCl over zone to be perforated.

12. Pull up tubing and install wellhead. Run down and snap into place. Pull 30,000 lb.[f]

13. Run annulus line. Pressure test tubing and annulus line to 2000 psi. Pressure against closed tubing and annulus valve.

14. Open tubing and annulus valve and pressure test casing and wellhead to 4000 psig.

15. Rig up and swab hole so that zone is under balanced at least 500 ft.

16. Run in through lubricator and perforate hole at desired intervals. Make all perforations in one run.

17. Flow back well. Swab if necessary. Test well if gas flows to surface.

18. Break out tubing and annulus lines, install ice pole and move off well.

[a]T.D. = Total depth.

[b]K.B. = Kelly bushing.

[c]E.U.E. = Type of thread.

[d]WOC - Waiting on cement.

[e]BOP = Blowout preventer.

[f]To use the Hyper Dome perforating gun the tubing must be 8-10 ft above zone to be perforated.

Metric conversions: 1. ft to m, multiply by 0.3048.
2. lb to kg, multiply by 0.4536.

and liquid components. Gases are vented to the atmosphere, liquids are stored in tankage. The spent liquids are returned to shore for approved land disposal to avoid any possible pollution of the Lake. The composition and environmental impact of these materials will receive further attention in later stages of the assessment program.

Since a successful well stimulation job will increase formation permeability locally to allow gas flow into the well, increasing amounts of natural gas will accompany the return of stimulation materials during the flowback process. At some point during flowback, fluid returns will constitute such a small fraction of the returns that it will become economically unfeasible to continue separation and collection. The Canadian Lake Erie drilling program assumes that fluid returns beyond this point are not a pollution hazard. Also, as more natural gas accompanies the flowback materials, the danger of explosion increases. Canadian Lake Erie operators shut-in the well when the flowback rate drops to approximately 37.8 L (10 gal)/min (Hurd and Kingston 1978). The steel piping is then disconnected and replaced with a neoprene hose that runs from the wellhead to the Lake surface. The hose is supported at the surface by two 45-gal drums (camel) housing both the hose and valving hardware (Bryant 1978--personal communication). The well is once again opened and allowed to vent to the atmosphere. Returns from the well, mostly gas at this point, are sprayed to the atmosphere as a fine mist. The well stimulation crew can monitor gas flow rate and composition to determine if the well can be economically produced. After this determination has been made, the well is shut-in and the camel apparatus removed. The well then awaits connection to an underwater collection system, restimulation, or plugging and abandonment procedures.

WASTE DISPOSAL

Regardless of drilling location, gas, liquid, and solid residues are routinely generated by natural gas development and production activities. Drilling fluids used for bit lubrication and blowout control are reused until they no longer demonstrate desired physical and chemical properties. Rock cuttings brought to the surface along with the drilling fluids are separated and discarded. Conventionally, in U.S. land-based operations, rock cuttings and drilling fluids are disposed of in pits dug onsite. Liquids are allowed to percolate into the soil leaving solid residues to be covered over in the pit. Gases from drilled formations may also accompany drilling fluids and escape to the atmosphere at the surface. For outer continental shelf offshore operations, special handling is required when H_2S is present in harmful concentrations (greater than 10 ppm) in these gases (U.S. Geological Survey 1976).

When wells require physical and/or chemical stimulation to increase gas flow, large quantities of liquid wastes may be generated. Over 75,700 L (20,000 gal) of liquid may be pumped into a host formation along with hundreds of thousands of cubic feet of pressurized gas. Depending on the characteristics of the formation, a major fraction of this liquid could return to the surface. For U.S. land-based operations, stimulation returns are often piped into a large metal tank to dissipate the hazardous energy of the high pressure foam that reaches the surface. The liquid material is allowed to flow into an onsite pit and percolate into the ground.

After well completion and attachment to a distribution pipeline, produced natural gas must be processed to meet distribution line requirements for H_2S, condensate, and produced water content. Most of the gas produced in New York, Ohio, and Pennsylvania meets distribution line standards without any processing. In cases where H_2S must be removed, solid residues generated from scrubber operations must be disposed of in approved landfill sites as regulated by state agencies responsible for solid waste. When the condensate fraction of gas is great enough to require removal, it is normally stored onsite and sold in bulk loads to refineries.

Formations containing brines are often encountered during the drilling process. Land-based gas production operations in states surrounding Lake Erie normally allow the small quantities of brines produced from the wellbore [approximately 0.0011 L/m^3 (8 gal/MMCF) of produced gas for southern Ontario wells (Lawler, Matusky & Skelly 1977)] to accumulate in a drip (convoluted piping) attached to the wellhead. In New York and Pennsylvania this liquid (brine and perhaps small amounts of unseparated condensates) is occasionally blown from the drips onto the surrounding land where liquids then percolate into the ground. In Ohio, regulations written to enforce state oil and gas laws (Ohio Oil and Gas Laws with Rules and Regulations, Chapter 1501:9-3) require that all produced waters be reinjected into approved wells.

Ultimate determination of the fate of gaseous, liquid, and solid residues generated by USLE natural gas development and production will depend on existing and new regulations promulgated under the Clean Water Act, Clean Air Act, Resource Conservation and Recovery Act, Safe Drinking Water Act, and other environmental laws. Further analysis of these regulations and corresponding state laws and regulations, in addition to knowledge about the physical and chemical characteristics of drilling wastes, is required in other phases of this assessment to provide additional perspective on the USLE waste disposal issue.

A number of mechanisms for residue disposition exist, these include discharge to the Lake, emission to the atmosphere, collection and disposal onshore in landfills or inspection wells, and treatment preceding onshore disposal. Most of the anticipated residues can be disposed of using available inspection-well or surface-disposal pond technology. The following discussion presents a summary of principles of injection well operation. Alternative disposal options and requirements are presented as an issue discussion (see p. 153).

Stimulation of limestone formations is normally accomplished by pumping an acid into the formation to disperse clays which could clog the flow of gas into the wellbore or to dissolve carbonates to create solution channels through which gas may pass. A typical treatment volume consists of 1.9 m^3 (500 gal) of HCl (Hurd 1977). Stimulation of sandstone formations requires hydrofracture. A liquid under high pressure is pumped into the gas formation until cracks form. Sand, pumped in with the liquid, wedges in the newly created cracks and keeps them open after the pressure on the fluid is relieved. The stimulating fluid is allowed to flow back out of the rock and is stored until it can be disposed of safely. (For a list of materials used in a typical fracturing operation see the section on Well Stimulation).

Disposal of gas-field liquid wastes by well injection has been practiced in the United States since the 1930s. In some cases the wastes have been returned to the ground through abandoned producing wells or dry holes. In other instances, wells have been drilled and equipped for the sole purpose of waste injection.

A disposal formation must contain sufficient voidspace and have a large enough hydraulic conductivity so that the wastes can be injected. It must also be isolated from all high quality groundwater and from exposure to the biosphere. The same formations which have trapped gas often meet these criteria.

The most common lithologies used for disposal formations are sandstones, conglomerates, limestones, and dolomites. Table 33 identifies the thicknesses and potential suitability of various formations in the vicinity of Lake Erie for liquid waste injection. Some of the formations that appear to be suitable may have to be rejected because they are aquifers.* The depths of the formations vary; in general, the oldest lie no more than 600 m (2000 ft) deep near the southwest corner of the Lake and 200 m (650 ft) along the southern shore and near the Michigan shore. Depths of overlying formations can be estimated respectively.

Hydraulic conductivities of rocks in most formations depend upon pore spaces as well as from fractures and solution channels. The hydraulic conductivity may be measured *in situ* by pump or slug tests. Laboratory tests on core samples, if available, are helpful for measuring primary hydraulic conductivity, but they cannot identify the effects of fractures. Sometimes a high clay content or a high degree of carbonate cementation reduces the hydraulic conductivity of the desired host formation. As previously discussed, acids can be injected into the formation to increase its hydraulic conductivity. The chemical composition of wastes disposed of must be compatible with formation mineralogy so that the solution process is not reversed. Hydro-fracturing is another acceptable method of increasing permeability provided the formations confining the one to be used for storage are not fractured in the process.

The areal extent of the host formation is also important. If it is small, or if the permeability decreases close to the well, exceptionally high pressures may develop during the waste injection. Undesired fracturing could result.

Gas well liquid wastes have been disposed of in formations as shallow as 60 m (200 ft) and as deep as 1800 m (5900 ft) (Latta 1973). The minimum depth, if not controlled by state regulations, should be determined according to the location and depth of the local aquifers and the likelihood of contamination of the biosphere. The overburden pressure at the depth of the potential host formation is critical in determining the injection pressures likely to cause fracturing. This value is site-specific.

Wastes may be injected into formations whose pore spaces initially contained air, natural gas, oil, or brines. They displace or mix with any initial fluid or gases. The gradient and hydraulic conductivity of the formation

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*Rock formations containing water in recoverable quantities.

Table 33. Suitability of Geological Formations in the Lake Erie Vicinity for Injection of Gas Well Wastes[a]

System	Formation	Lithology	Maximum Thickness (m)[b]	Suitability for Injection
Mississippian	Berea[M,O]	Sandstone	?	Good
Devonian	Upper Devonian[M,O,P,N]	Shale	390[O,P,N]	
Devonian	Onondaga[P,N,O] Bois Blanc[M]	Chert, dolomite Limestone	46[N] 91[M]	Depends upon permeability
Devonian	Oriskany[P] Springvale[O]	Sandstone	21[O]	Good if sufficient extent, thickness, and permeability
Devonian	Helderberg[N,P]	Limestone	9	Depends upon permeability and extent
Silurian	Cayugan[M,N,O,P]	Halite, anhydrite, shale, dolomite	121-210[O]	Confining bed
Silurian	Lockport[O,P]	Dolomite	106[O,P]	Limestone barrier reefs are gas reservoirs
	Niagra[M,N]-Clinton[P,M]	Dolomite-shale		Depends upon extent and permeability
	Newberg[O]	Dolomite	Thin	Porous saline, good if large enough
Silurian	Rochester[M,O,P,N]	Shale and minor dolomite	4[M]-30[P]	Confining bed
Silurian	Packer Shell[O]	Limestone, dolomite	3-9	Poor, too thin
	Reynales-Irondequoit[P,N]			
Silurian	Medina[O,P,N]-Whirlpool	Sandstone	Combined total-15	Good, sandstones
Clinton[O,P]	Cabot Head	Shale and sandstone		Carbonates, depends upon extent and permeability
	Grimsby	Sandstone and shale		
	Thorold	Sandstone		
	Manitoulin[O]	Limestone-dolomite		
	Brassfield[O]	Limestone-dolomite		
	Niagra-Clinton[M]	Dolomite-shale		
Ordovician	Queenston[N,P,O] (Juniata)	Shale	30[O]-240[N]	Confining layer
	Cincinnatian	Shale	300-550	Confining layer
Ordovician	Trenton[M,O,P,N]	Limestone, dolomite	30[M]-150[P]	Depends upon permeability
Ordovician	Black River	Limestone, dolomite	84-155	Depends upon permeability
Ordovician	Glenwood	Argillaceous dolomite	0-8	Poor
	Shadow Lake	Dolomite, sandstone		
Cambrian	Upper Cambrian	Dolomite, sandstone	?	Good if of sufficient extent; good secondary porosity
Cambrian	Kerbel[O]	Sandstone	15-30[O]	Good
Cambrian	Mt. Simon[M,O] Potsdam[P,N]	Sandstone	38	Good

[a]Based on data from Briggs (1968), Clifford (1973), Hardaway (1968), and McCann et al. (1968).

[b]To convert m to ft, multiply by 3.2808.

M = Michigan, O = Ohio, P = Pennsylvania, N = New York.

determine whether the wastes will migrate once they are injected. One hazard to be avoided is the displacement of brines from a previously localized area into a freshwater aquifer.

Generally, gas-well wastes are injected into a formation that is separated by one or more aquicludes* from all aquifers of good quality water. Wells penetrating these barriers to groundwater migration must be adequately sealed to prevent contamination.

Injection wells may be drilled specifically for waste disposal or adapted from gas wells that never produced or are now depleted. A typical well drilled for the purpose of waste injection, shown in Figure 11, is a lined hole containing injection tubing bedded in a gravel pack at the disposal horizon. A packer seals this level from the remainder of the well so that high pressures can be developed for injection. The aboveground equipment on the waste injection line includes a master valve, pressure and rate regulators and recorders, and a filter system. The wastes must be filtered so that solids will not clog the disposal reservoir. A backwash or other filter-cleaning system is usually an important part of the apparatus. Aboveground equipment also includes a regulator for the pressure of the annulus fluid (Meers 1973).

Frequently a well penetrates more than one potential disposal formation. Each formation is logged and tested at the time the well is drilled. The lowest formation is used first for injection. Should it become clogged, a higher formation may be developed. The wastes may be injected under the pressure of gravity or may be pressurized to over 10,300 kPa (1500 psi) (Warner and Orcutt 1973). The pressure used depends upon the force needed to fracture the receiving formation. Sometimes allowable pressure limits are set by state governments. Injection rates may be as high as 3×10^{-2} m^3/s (500 gpm) (Warner and Orcutt 1973). The pressure on the annulus fluid is maintained at 690 kPa (100 psi) above the injection pressure. Leaks in the injection tubing or the packer are detectable by a sudden drop in the annulus fluid pressure (Meers 1973).

When waste injection is terminated, the well is plugged by injecting cement plugs at every opening. The well is then capped.

PLUGGING AND ABANDONMENT OF WELLS

Many wells that are drilled are dry holes initially and must be plugged so that they are permanently sealed from the Lake. All wells must be abandoned and plugged after depletion. The proper way to plug a well is to place cement plugs in the wellbore. These plugs must be long enough and numerous enough to prevent any vertical flow of fluids in the wellbore so that fluids from one geological formation cannot flow up or down the wellbore to another formation and contaminate or pressurize it.

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*Strata impermeable to water.

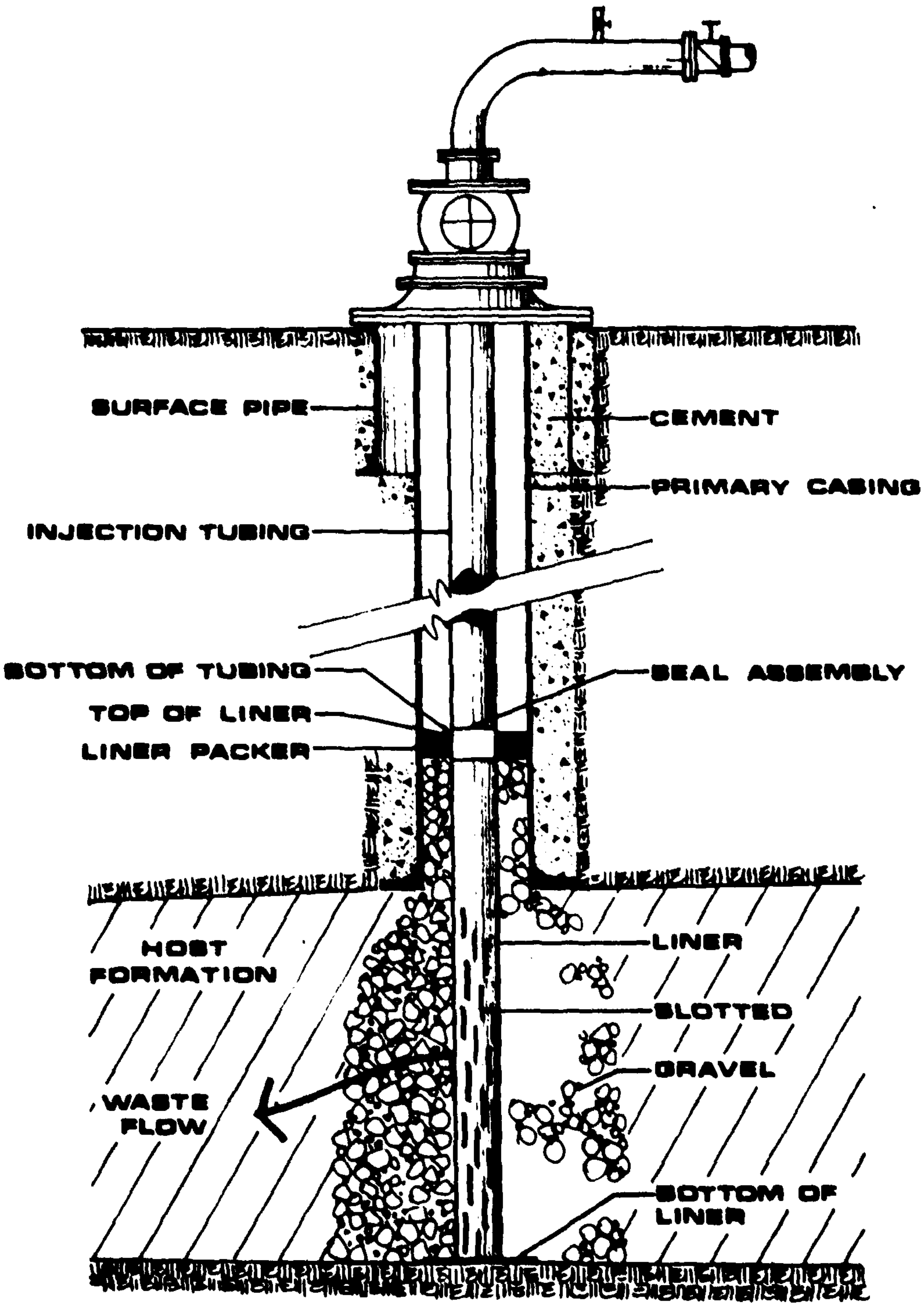

Figure 11. Schematic Diagram of a Typical Waste-Disposal Well. Adapted from Meers (1973).

Ideally, the entire wellbore should be filled with cement. In reality, as a matter of economy, this is not done at the present time. The following description illustrates the Canadian plugging program (see Hurd and Kingston 1978).

Plugs must be set across any fluid-, oil-, or gas-bearing zone. The plugs should extend 15 m (50 ft) above and below these zones; the interval between plugs can be filled with mud.

One plug should run from the Queenston (upper Ordovician) to approximately 15 m (50 ft) above the Thorold (treated in this report as part of Clinton, lower Silurian) layer. The second plug should extend from in the Guelph* (upper Silurian) to 61 m (200 ft) or more above it. The third plug should extend from in the Salina to above the Bass Islands (top of upper Silurian) deposits. The fourth plug should extend through the Dundee (middle Devonian) to 15-30 m (50-100 ft) above it. The fifth plug should be approximately 30 m (100 ft) long and must extend up to the lake bottom. The other plugs should be from 61 to 91 m (200 to 300 ft). Slurry weights should be 1.76 kg/L (14.7 lb/gal). Any other gas or water zone encountered must be included in the plugging program. The plugging program is subject to revision at the discretion of the government inspector.

PRODUCTION OF NATURAL GAS

In excess of 28.3 billion m^3 (100 BCF) of gas have already been produced from the geologic strata under Canadian Lake Erie waters. The existing Canadian collection system from the wellheads to the shore facilities is simple and will probably be used in any USLE program.

Pipeline construction in Lake Erie has consisted principally of welding sections of pipe together onshore and then using a tugboat to tow the pipe into the Lake. Flotation devices attached at fixed intervals along the pipe are used for buoyancy during transport. Once the pipe has been placed in position, it is submerged and connected by divers using dresser couplings. The main transmission lines vary in diameter from 10.2 to 20.3 cm (4 to 8 in.) with an overall wall thickness of 0.6 cm (0.25 in.). The laterals from the main line to each individual well are 5.1 cm (2 in.) in diameter and have a wall thickness of close to 0.48 cm (3/16 in.). These are usually connected to the wellhead assembly by a 5.1 cm (2 in.) neoprene hose rated, along with the entire pipeline system, at 14,000 kPa (2000 psi). Manual and automatic check valves are strategically placed along the line to permit the shutting in of wells, individually or as a group, should the need arise. In recent years, some dresser couplings have been removed and the joints welded. These continuous weld-transmission lines minimizing minor leaks and pipeline breaks will probably continue to be used. The pipelines are laid directly on the bottom of the lake and reinforced at the shoreline to prevent ice damage. At the shore, the onshore transmission lines direct the gas to the compressor and metering stations from which it is delivered to the main distribution lines.

*Guelph, Salina, Bass Islands, and Dundee are names of stratigraphic units on the Ontario side of the Lake. Exact equivalents to formations on the U.S. side, as outlined in the Geologic Overview, are not involved.

Pipelines at the shoreline in the United States would probably be buried, beginning about one half mile off the lakeshore (see also pp. 160-162). Distribution lines leaving the shore facilities would also be buried.

Based solely upon technological and economic criteria, any USLE underwater collection system more than a half mile from the lakeshore would probably not be buried* since burying the lines would be more costly than laying them on the lakebed. Buried lines would also be less accessible to maintenance crews in the event of pipe breaks or of other problems requiring site-specific attention. (The quickest way to make repairs has proven to be above water, with the welded lines lifted to the surface by a barge-mounted crane.) Environmental considerations must also be accounted for in the final decision concerning the location of underwater pipelines. Burial of pipelines would cause resuspension of lake sediments similar in nature, although not necessarily in magnitude, to that caused by the placement of jack-up rigs. Final decisions concerning the placement of pipelines (on or below the lakebed) must be based on a cost-benefit analysis evaluating the relative benefits of pipeline protection through burial against the potential for environmental degradation and increased inaccessibility and costs.

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*It should be noted that Pennsylvania has included requirements for pipeline burial in its Lake Erie Natural Gas Lease (Pa. Dep. Environ. Resour. 1977). The lease stipulates that "all pipelines under shipping lanes and anchorages must be buried."

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TECHNOLOGICAL OVERVIEW--ACCIDENTS

INTRODUCTION

The development of natural gas as an energy resource is inherently dangerous due to the flammability and pressures of gases associated with the development and production process. When development and production activities are moved to a freshwater or marine environment (offshore) the potential consequences of any accident becomes more severe. Personnel cannot easily be moved out of the range of explosion and fire because of the limited size and mobility of offshore equipment. Losses to property can be greater simply because offshore equipment is more capital intensive than is land-based equipment. Also, materials released as a result of accidents can disperse quickly in an aquatic environment making containment and clean-up operations difficult and expensive. Thus, accident prevention is critical to the industry.

Offshore drilling technology will be reviewed with respect to causes and consequences of accident events. However, since most offshore activities are initiated to develop and produce oil as well as gas resources, it proved impractical to separately review gas (as distinct from petroleum) development and production accidents. Many of the causes and consequences of gas- vs. oil-related accidents are similar and, in fact, inseparable with respect to the specific resource being developed.

Despite obvious differences in environmental and geological conditions and in the operational scale between offshore marine and Lake Erie drilling programs, it was hoped that a review of offshore drilling history would help identify categories of accidents that could result from any offshore drilling activities. Furthermore, it was hoped that a review of Canadian drilling history in Lake Erie would provide a sharpened perspective of the types of accidents that have occurred given the environmental and geologic conditions and scale of operations that occur in Lake Erie. The ultimate goal of reviewing offshore accident history is to construct a framework in which the potential risk of personal injury, loss of life, property damage, and environmental harm can be weighed against the benefits of developing natural gas resources.

Accidents resulting from worldwide offshore mobile-rig drilling activities have been summarized for the period from 1955 to 1978 by Offshore Rig Data Services (1978). Of the 85 accidents reported, 52 were associated with jack-up rigs (Table 34). The relatively large percentage of jack-up accidents reflects the wide-scale use of this rig design for offshore drilling as well as its susceptibility to accidents. The original data base was reorganized by project staff according to the operational mode in which each accident occurred. It is not possible to clearly determine from the original data base whether the accident resulted from human error, equipment failure, severe weather, or unpredictable drilling conditions. The data do show that there are certain operational phases in which accidents occur with some frequency: during the process of towing a drilling rig to a site or while it is being

Table 34. Summary of Worldwide Jack-Up Rig Accidents between 1955 and 1978[a]

Accident Description	Number of Accidents per Category
1. Structural damage or capsize while in tow	
Normal weather	3
Bad weather	8
2. Structural damage during jacking-up process	8
3. Rig capsize at site	
Normal weather	5
Bad weather	2
4. Leg failure at site (may or may not lead to capsize)	
Normal weather	7
Bad weather	1
5. Blowout during drilling	
With fire	6
Without fire	6
6. Structural damage to sited rig (resulting from miscellaneous causes not reported above)	
Normal weather	1
Bad weather	5
Total jack-up rig accidents reported	52

[a]Compiled by Offshore Rig Data Services (1978).

jacked into position onsite. Also, the stilted jack-up platform is vulnerable to wave forces during storm events. Although the rig is designed to withstand these forces, continued stress, rig construction errors, and storm events exceeding the design capacity of the rig can result in structural damage or capsize. Despite the lack of mobility of the rig while drilling, visual and audible warning devices seem to effectively reduce the potential for rig-vessel collisions. Of the 52 accidents reported, none was the result of an open water collision between a stationary rig and a mobile vessel.

Offshore rig accidents have also occurred as a result of the ignition of flammable materials on board the rig.

There is a potential for encountering pressurized strata during the drilling process that could result in loss of well control despite the use of blowout prevention equipment. Depending on the nature and quantity of the released materials (oil or gas), release pressures, and the timing of the blowout, explosion and fire could result. Blowouts can often be attributed to a combination of factors, including human error, equipment failure, severe weather, and unpredictable drilling conditions.

The data base provided by Offshore Rig Data Services does not consistently identify the consequences of accidents. Between 1975 and 1978, the data base includes information on the value of property damage that resulted from each accident. Depending on the severity of the accident, this amount varied from insignificant monetary losses to loss of the total value of the rig (tens of millions of dollars). No information on personal injury, loss of life, or environmental damage was reported for any of the accidents.

Of the total 85 accidents reported for all offshore mobile rig drilling activities, only one involved the Canadian Lake Erie drilling program.* This accident occurred in 1975 on a jack-up rig. Although the nature of the accident is not reported, conversations with Canadian government representatives (Hurd 1978 and Bryant 1978--personal communication) revealed that the accident resulted from a failure of the jacking mechanism. There was no report of environmental damage as a result of this accident.

A review of southeastern U.S. offshore drilling and production accidents is in progress to aid in understanding problems relating to contemporary technology used in the United States. Accidents resulting from outer continental shelf (OCS) activities in the Gulf of Mexico have been summarized by the Conservation Division of the U.S. Geological Survey since 1956. The OCS data describe the consequences as well as the causes of each reported accident. Causal characteristics of accidents are divided into two categories; (1) "the uncontrollable flow of fluid from a wellhead or wellbore" (blowout) or (2) "explosions or fires directly related to drilling, producing, storing, or transporting oil and gas on or from OCS leases" (U.S. Geological Survey 1978). Accidents are categorized into pipeline breaks or leaks, significant pollution incidents, and major accidents on the basis of quantity of released materials, injury to humans, and resultant property damage. Since the OCS data base has not as yet been fully examined, a summary is not included in this report.

In addition to reviewing worldwide and U.S. offshore accident data, an attempt was made to obtain a summary of Canadian Lake Erie gas development and production accidents. Although communication with government and petroleum industry representatives active in the Canadian drilling program has led to an initial perspective on the frequency and magnitude of Lake Erie drilling and production hazards, detailed analysis must await the availability of a complete, historical data base.

Using the described accident data bases, an overview of Lake Erie drilling conditions, and information derived from study participants and others experienced in offshore drilling, the development and production activities in the Canadian Lake Erie gas development program were evaluated in order to identify the types of accidents that might occur from implementing a U.S. Lake Erie drilling program. The approach taken was to describe a most likely and worst-case accident for each of the drilling and production activities defined in

*Newton (1964) reported that in 1957 a "floating-type tower" consisting of a tower unit placed on top of a submerged platform was tested on Lake Erie. During the final erecting and guying procedure, the complete unit capsized into 14 m (45 ft) of water. This accident was not reported by Offshore Rig Data Services.

the Technological Overview. It should be emphasized that use of these descriptions does not imply that accidents will occur with any specific frequency or even as described. The descriptions are intended to serve as a framework useful for assessing potential environmental damage; they are a part of the continuing research and analysis component of the study. More detailed knowledge of the chemical composition of released materials and of physical characteristics of the Lake and atmosphere is needed before the environmental consequences of potential accidents can be evaluated in depth.

Following the description of potential accidents is a summary of the existing Accident Contingency Plan for Lake Erie. This summary provides background on institutional arrangements established in the United States and Canada for responding to and effectively controlling the consequences of any accident on Lake Erie. However, no attempt has been made to evaluate the potential effectiveness of this plan.

DESCRIPTION OF POTENTIAL ACCIDENTS

Siting of Drill Rig or Vessel

Historically, site preparation for the location of a drilling rig for the purpose of drilling a well has been among the most neglected of the operations in drilling offshore wells. Careful selection and preparation of the site is required prior to locating the rig. Knowledge of the nature of bottom sediments and topography at the particular location are essential in order to avoid placing a jack-up rig on unstable bedding which could result in rig capsize. In the last few years, more attention has been paid to this aspect of drilling; consequently, since 1975 there have been fewer accidents resulting from poor site preparation than from any other cause (Offshore Rig Data Services 1978).

The most common accident involving a jack-up rig is the collapse of one or more legs when the rig is jacked into drilling position. The legs, the most vulnerable part of a jack-up rig, are subject to stress and fatigue which can cause collapse. In most instances, the failure of the jacking mechanism or the failure of a leg does not result in loss of material and equipment; nor is it likely to cause loss of life or injury to personnel, although property damage may be high. Accidents involving jack-up rigs are usually the result of all three of the normal causes of accidents: equipment failure, human error, and bad weather.

The most disastrous accident that could occur during rig siting is the capsize of the rig with loss of everything on board to the water. Since the rig is not prepared for drilling during placement, the likelihood of working amounts of drilling mud and other material being on board is small. However, some drilling mud would have been left on board from the last location and, in such an event, this material would be lost to the water. Depending on whether or not the rig had been refueled for resumption of drilling, as much as 79 m^3 (500 bbl) of diesel fuel could also be lost, as could any mud additives, cement additives, or lubricants being stored on board.

Surface Hole Drilling

In drilling the surface hole, the most probable accident event assumed is an encounter with pressured shale gas. State-of-the-art technology to control anticipated shale gas encounters is available. In the worst case, a complete blowout during open-cycle drilling is assumed. A blowout can result in loss of life, rig capsize, total destruction of the rig, and release of materials on board the rig to the water. The typical rig anticipated for Lake Erie use would have a capacity for storing 32 m^3 (200 bbl) of drilling muds and 79 m^3 (500 bbl) of diesel fuel (Ocean Industry 1977). Other materials stored on board the rig during drilling could be released as a result of a rig's capsizing; these materials include mud additives, cement, cement additives, and lubricants. In addition, a worst-case blowout accident during open-cycle drilling would preempt well control during rig capsize. Assuming the worst possible combination of events, the wellbore could be in contact with pressurized production strata during the accident. A potential result could be the total displacement of all muds in the drillstem by pressurized gas. Recognizing the geologic characteristics of eastern and central basin production strata, only gas would be expected to accompany the release of drilling muds from the severed drillstem. It would be almost impossible to realistically estimate the potential for encountering significant amounts of wet hydrocarbons and produced waters in specific locations. Nor would it be feasible to predict the amount of gas that might actually escape from production strata during a blowout accident. A discussion of the potential danger from the uncontrolled release of dry gas is presented in the Underwater Collection System section.

Casing Placement and Securement

During the setting of casing in the well and its securement by means of cementing, the most probable accident is the dropping of the casing string in the hole before the total amount of pipe has been lowered. In most cases this is a result of human error; in some instances, equipment failure is to blame. Bad weather could complicate the situation and become a contributing cause to the accident. A worst-case accident involving the lowering of casing sections and cementing of casing strings would result from an inability to recover the dropped pipe and clean up the hole. As a result, the rig would have to be moved from the site after the fouled hole had been plugged.

Very few accidents result from placing cement between the casing strings and surrounding strata. The few that do occur are overwhelmingly the result of equipment failure. Cement must be forced down the inside of the casing string until it reaches the bottom of the wellbore. Continued pressure forces the cement upward between the casing pipe and surrounding strata. A worst-case accident would occur as a result of pump failure while the cement was being forced down the casing string. In such a situation, the cement would be unable to move out of the pipe and would eventually harden. This, although a troublesome experience, would not necessarily be a dangerous one. Sections of casing pipe containing hardened cement would have to be recovered before the well could become fully operational.

Drilling to Depth

During this operation, the most likely accident would be equipment failure resulting in some property damage. Equipment failure during drilling rarely results in injuries to personnel; nor does it often result in release of materials to the water column. A worst-case accident would be equivalent to that described for loss of well control during surface hole drilling except for the fact that closed-cycle drilling would be in effect. It is assumed that rig capsize would sever the riser pipe rendering the BOP equipment ineffective.

Well Stimulation

The typical well-stimulation barge currently used by Canadians would probably be adopted for use in USLE if a gas development program is implemented. The barge measures 15-21 m (50-70 ft) in length and approximately 9 m (30 ft) in width (Brooks 1978--personal communication). When fully loaded, it has a draft of no more than 1.8-2.4 m (6-8 ft) making it a very versatile vessel for operation in all water depths including shallow waters adjacent to the shore. Normally, barges do not operate under their own power and must be towed to the drill site. The typical stimulation barge carries the power-driving machinery and pumps needed to inject well stimulation materials down the wellbore and into the production strata. Also on board are a manifold system and tankage necessary to separate liquids from gases and to contain liquid backflow from the well after injection. In the typical Canadian well-stimulation operation, the barge carries enough materials to stimulate three wells per trip (Brooks 1978--personal communication). Since both acidizing and fracturing can be accomplished from the barge, materials needed for both operations can be carried on board. The following materials would be carried by the typical well-stimulation barge when fully loaded (Burd 1978--personal communication). The quantities listed represent the minimum amounts needed to perform these average fracturing operations. Actual quantities carried may be slightly larger than those reported:

HCl (15%), 5680 L (1500 gal)

Sand, 51,700 kg (114,000 lb)

Surfactant, 284 L (75 gal)

$CaCl_2$, 3400 kg (7500 lb)

Gel, 1090 kg (2400 lb)

CO_2, 17,000 m^3 (600,000 SCF)

For fracturing operations, the rate at which materials are injected into the wellbore is approximately 1.77 L/s (28 gal/min) and pressures used may be as high as 28,000 kPa (4000 psi).

The most likely accident during well stimulation would be the result of a break in one of the high pressure lines of the pumping system. The high pressure system is fitted with valves that can quickly shut off the flow of materials into the broken lines. The small amount of stimulation material contained in the line between cut-off valves would be lost to the water. Serious injury could result to anyone in the immediate vicinity of the line break. Conversely, relatively little property damage would be anticipated.

The transfer of bulk liquid materials from dock tankage to barge tankage requires connection and disconnection of hoses. During loading and offloading operations in port, minor amounts of liquid [less than 38 L (10 gal)] can be assumed to be routinely lost to the water. Diesel fuel and HCl would constitute the most frequent bulk liquid loads that might be spilled during loading and offloading.

Under a worst-case accident assumption, the well-stimulation barge could capsize or sink as a result of bad weather or after a collision with another vessel or object. It would then be assumed that all of the tankage would be broken open and the contents, as described above, released to the water.

Transportation of Materials to and from the Drilling Site

Work-boats keep drilling rigs and well-stimulation barges supplied with the necessary materials to maintain uninterrupted drilling and stimulation activities. A work-boat may contain miscellaneous tools, pipe and equipment, as well as sacks of drilling mud components, and diesel fuel. The work-boat also provides a means of transporting crew replacements and industry personnel between the work site and port.

These boats vary greatly in size; the average for Lake Erie work-boats would be about 15 m (50 ft) long by 4.6 m (15 ft) wide (Underwater Gas Developers 1976). Deck space for carrying loads varies from 5.2 × 7.6 m (17 × 25 ft) on a large work-boat, to 4.6 × 4.1 m (15 × 13-1/2 ft) on smaller boats. Fuel tanks on board each boat provide replacement loads for drilling rigs and barges, as well as fuel requirements for its own engines. The larger boats carry approximately 6800 L (1800 gal) of diesel fuel, whereas the smaller ones carry as little as 760 L (200 gal).

Accidents aboard work-boats vary widely. The most likely accident would occur during the transfer of materials from the boat onto the drilling rig. Cables may break and hitches may loosen with the result that the material being transferred could drop on the boat or into the water.

In the worst case, the work-boat may sink as a result of a collision with another vessel or object in the Lake, or capsize during bad weather. Due to the varied nature of work-boat cargoes, the range of materials that might be released to the water as a result of such an accident could include any of the supplies or replacement parts necessary for maintenance of normal drilling operations as well as wastes being transported to shore. Under worst-case assumptions, the entire fuel load could be lost, as well as sacks of cement and drilling mud components. Property damage could amount to total loss of the worth of the vessel and its cargo. There is also a significant possibility of injury to those on board at the time of the accident.

Plugging and Abandoning a Well

As described in the technological overview of normal operations, abandonment operations for dry holes or retired production wells involve the placement of a number of cement plugs at appropriate depths in the wellbore. The plugs must be long enough and numerous enough to prevent any flow of fluids in the wellbore. Specifically, cement must be placed across any fluid-, oil-, or gas-bearing zone and must extend 15 m (50 ft) above and below these zones.

The interval between plugs can be filled with either mud or water. (Also see section on Plugging and Abandonment of Wells on p. 112.)

The most probable accident expected to occur would be the improper placement of any one plug in the wellbore. This could be attributable to human error, but is generally the result of the failure of cementing and packing equipment to function properly. In addition to the plugs placed over fluid, oil, or gas zones, other cement plugs are located at designated depths in the wellbore. In the event that misplacement of any one plug allowed migration of fluid or gas through the previously perforated casing, vertical migration of materials would be checked by one of the other plugs. The final surface plug extending 30 m (100 ft) from the lake bottom would be assumed to be an effective block to any fluid or gas migration from the wellbore to the lakebed and consequently to the water column.

Depending on the physical and chemical characteristics of the strata surrounding the wellbore, casing metal and cement plugs could possibly be corroded over time. Under this worst-case assumption, fluids or gases within strata adjacent to the wellbore could migrate upward or downward through corroded casing and plugs. This migration could also take place through spaces created by corrosion of cement surrounding the casing. There is a potential for contamination of any freshwater aquifer located above or below the point of corrosion. If subsurface pressures were sufficiently high, migration of pressurized liquids (probably brines and small amounts of condensates) could reach the lakebed and ultimately the water column (see Plugging and Abandonment of Wells).

Underwater Collection System

The most probable accident involving the underwater collection system would be pipe failure. There are two likely causes of pipe failure. The pipeline may be snagged and broken by a dragging anchor, chain, or fish net. This would be attributable to human error in that the most recent navigation charts will show the locations of underwater pipelines as navigation hazards. The other mechanism by which pipe failure is likely to occur is ice scour during winter storms. Assuming that landfalls would be buried as a means of minimizing this risk, in a worst-case situation, ice scour could extend to depths where the pipeline is exposed.

Pipeline ruptures should not cause a major loss of material if proper automated check valves have been installed in the pipeline and if they perform as prescribed. The actual volume of material lost would be determined by the distance between the check valves, the internal diameter of the pipe, and the pressure of the gas in the pipe. Assuming conservative worst-case conditions, the check valves will be spaced approximately 1.6 km (1 mi) apart, the internal diameter of the pipe will be 15 cm (6 in.), and upper range of expected reservoir production pressures will yield pipeline pressures not exceeding 3.45 MPa (500 psi). Under these conditions, 1000 m^3 (35,500 ft^3) of gas would be released. Assuming that all of the lost material is combustible natural gas, it is possible to calculate the maximum area within which ignition is possible.

The theoretical maximum velocity of the gas, assuming a small break [3.9×10^3 mm^2 (6 $in.^2$)], is calculated by Bernoulli's equation (Halliday and Resnick 1966):

$$V = \left[\frac{2(P_g - P_a)}{e_g}\right]^{1/2}$$

where P_g = gas pressure = 500 psi = 3.47×10^6 Pa

P_a = atmospheric pressure = 14.6 psi = 1.01×10^5 Pa

e_g = gas density in pipe = 4.43×10^{-2} g/cm^3 (4.43×10^1 kg/m^3)

With these values, the maximum escape velocity is 389 m/s (870 mph). (In an actual break, the escape velocity will be lower, due to the break size, turbulence, and pressure drops as time passes.) Assuming this escape velocity, and that 1000 m^3 (35,500 ft^3) of gas lie between check valves, the release takes place in approximately 650 s with a release rate of 1.97×10^3 g/s.

The dispersion rate at the atmosphere will determine the size of the area subject to ignition. The "Puff" method, suggested by Turner (1970) is used. The basic equation for a ground-level release is

$$X(x,y) = \frac{2Q}{(2\pi)^{3/2}\,\sigma_x\sigma_y\sigma_z}\left\{\exp\left[-\frac{1}{2}\left(\frac{x-ut}{\sigma_x}\right)^2\right]\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\right\}$$

Q = release rate = 1.97×10^3 g/s

σ_x, σ_y, σ_z = dispersion coefficients, distance dependent

x = downwind distance

u = wind velocity

t = time

y = crosswind distance

For maximum concentration, the "centerline, centerpoint" concentration is assumed. Thus, Y = 0 and x = ut at 3 km (1.9 mi)

$$X(3\text{ km}) = \frac{(2)\ (1.97 \times 10^3)}{(2\pi)^{3/2}(230)(230)(180)} = 26.3\ \mu g/m^3$$

The flammability limit is 64.6 $\mu g/m^3$. Thus, the cloud will be flammable for less than 3 km (1.9 mi) downwind. The crosswind distances (y distance to reach limit of flammability) are:

Distance Downwind	Crosswind Distance
0.5 km	122 m
1.0 km	166 m
2.0 km	76 m

The cloud would appear as in Figure 12.

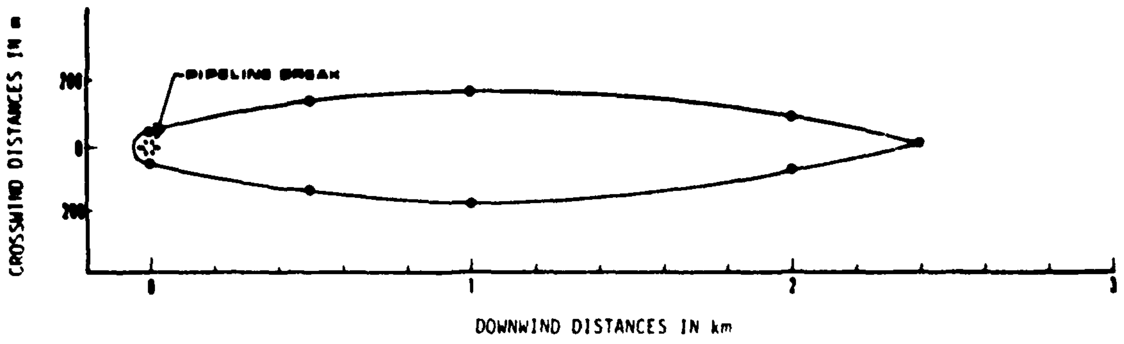

Fig. 12. Possible Natural Gas Dispersion Cloud as Predicted by the "Puff" Method for a Pipeline Break.

Gas produced from the well includes a hexane-plus (or liquid condensate) fraction and hydrogen sulfide (H_2S). Typical hexane-plus fractions account for 0.03 percent of the produced gas averaged from Canadian Lake Erie data (Ont. Dep. Mines and Northern Affairs 1970). Since 1000 m^3 (35,500 ft^3) of gas would be lost under worst-case conditions, the total loss of liquid condensates would be 5.6×10^{-4} m^3 (0.15 gal). No assumptions have yet been made concerning the pattern of dispersion, or of concentrations of released condensates. The physical and chemical nature, and hence the contamination potential, of released condensates will be addressed in later phases of this assessment.

Typical H_2S content is 0.32 g (5 grains) H_2S per 2.8 m^3 (100 ft^3) of gas, resulting in a total release of 23 g (359 grains) of H_2S gas. Calculating dispersion of this H_2S gas by a Gaussian model, the downwind concentrations of H_2S at 100 m (328 ft) from the break is conservatively estimated to be 153 $\mu g/m^3$, and 19 $\mu g/m^3$ at 1000 m (3280 ft). These concentrations may result in a noticeable odor for some minutes, but no long-term impacts are anticipated.

Landfall

The most probable accident for landfalls would be the breaking of the lines on shore by bulldozers, trenching machines, ditch diggers, and other types of earth-moving equipment. This, the most common type of accident, is almost totally attributable to human error. Such an accident could be prevented by proper identification of the location of the lines by the individual responsible for the digging operations or other uses of earth-moving equipment; the location of all dangerous pressured lines in their area should be ascertained. The loss of material from this type of accident would be very limited and should be controlled to the amount between the automated shut-off valves. The worst possible case would involve a fire which could easily be started if there were sparks, fire, or any other ignition source available.

Land Facility for Processing and Compression

At a land facility for processing and compression, the most likely cause of damage would be equipment failure. Human error is sometimes responsible for accidents; for example, if valves are improperly operated or gauges incorrectly read, such incidents could lead to total mechanical failure of processing and/or compression equipment. Bad weather could also lead to accidents at the land facilities, but these occur very infrequently. Generally these are minor situations resulting in very little property damage.

Land Distribution Systems

The most likely accident to occur in distribution networks would be line breakages. These could occur for many reasons, primarily as a result of earth-moving equipment striking lines and causing breaks. A worst-case situation would involve a pipeline without a sufficient number of control valves in the system allowing for quick shut-off and easy venting to the air of the gas contained in the broken section of the line. Fires could result from the breaking of these lines. This could be serious since land distribution systems normally use large-diameter lines [20-30 cm (8-12 in.) or more in diameter] and have high pressures [5500 kPa (800 psi)]. If ignited, the released gas could result in a large conflagration.

CONTINGENCY PLAN

The primary goal of the National Oil and Hazardous Substances Pollution Contingency Plan (40 CFR §§ 1510.1 - 1510.54; hereinafter cited as National Plan) is to control and remove discharges of oil and hazardous substances* from the navigable waters of the United States and adjoining shorelines (40 CFR § 1510.2). Key sections of the plan provide for coordination among federal agencies; identification, procurement, and maintenance of equipment and supplies; a system of surveillance and reporting designed to ensure the earliest possible notice of discharges; and a procedure for documentation and the recovery of costs. The National Plan is supplemented by the Great Lakes Coastal Region Contingency Plan (U.S. Coast Guard 1975; hereinafter cited as Great Lakes Plan) and numerous subregional contingency plans (U.S. Coast Guard 1978). Each of these plans offers more detailed information to be applied in localized areas.

Complete responsibility for implementing the National Plan at the site of a spill has been assigned to the federal on-scene coordinator (OSC) (40 CFR § 1510.36). For spills in Lake Erie, the OSC will be provided by the United States Coast Guard [40 CFR § 1510.36 (b)(2)]. The Coast Guard has predesignated the captains of the ports of Buffalo, Cleveland, and Toledo as OSCs in their zones (Great Lakes Plan § 1470). The OSC for spills on inland waters is to be provided by EPA [40 CFR § 1510.36 (b)(1)]. To avoid confusion, jurisdictional boundary lines between the Coast Guard and the EPA have been established at the mouths of rivers and canals (Great Lakes Plan § 1408).

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*Regulations issued in Fed. Reg. 43: 10474 (1978) defining hazardous substances are being challenged in the courts. Manufacturing Chemists Association v. Costle, Environ. Reporter Case 2014 (W.D. La. 1978).

Having arrived at a spill, the first duty of the OSC is to determine whether the actions taken by the person responsible for the discharge are sufficient. If they are, the OSC will remain at the site to observe and provide such advice or logistical support as may be necessary. In the event that the party in violation has not and does not intend to undertake appropriate actions, or if the responsible party is unknown, the OSC will institute and supervise a federal response [40 CFR § 1510.21 (b)]. In so doing, the OSC may request aid from any federal agency that can provide it [40 CFR § 1510.21 (f)]. Funds for these operations are available through the National Pollution Revolving Fund established under section 311 of the Federal Water Pollution Control Act of 1972 [33 USC § 1321 (k), as amended by Pub. L 95-217].

To assist the OSC during a pollution incident, the National Plan has established a Regional Response Team (RRT) made up of five primary agencies and five advisory agencies (40 CFR § 1510.34) (Table 35). Representation from the impacted state or municipality is encouraged [40 CFR § 1510.34 (c)]. The RRT is activated automatically in the event of a major or potentially major discharge and upon oral request from any primary agency during other pollution emergencies [40 CFR § 1510.34 (d)]. The team's actions are coordinated by a chairperson, drawn either from the Coast Guard or EPA depending on the location of the spill. The Coast Guard will chair the team for spills in the Lake (Corbett 1977). In addition to providing the OSC with contingency data, experienced advice, and technical information during spills, the RRT is responsible for replacing the OSC when necessary, conducting advance planning, and preparing the Regional Contingency Plan. To foster interagency cooperation and a smoothly functioning response mechanism, the RRT meets quarterly (Corbett 1977).

Table 35. Regional Response Team Components

Primary	Advisory
Coast Guard	Department of Energy
Environmental Protection Agency	Department of State
Department of Defense	Department of Justice
Department of the Interior	Department of Housing and Urban Development
Department of Commerce	Department of Health, Education, and Welfare
Impacted State (not mandatory)	
Impacted Municipality (not mandatory)	

Source: 40 CFR § 1510.5 (n) (o).

The National Plan has created two other bodies that can provide assistance during a pollution incident. The National Response Team is responsible for national planning and coordination (40 CFR § 1510.32); it will be activated in the event of a pollution discharge that exceeds the response capability of the region in which it occurs (National Plan, Annex No. II § 1203.1). The National Strike Force is composed of Coast Guard personnel trained in spill response techniques. These personnel are divided into three teams--Atlantic, Pacific, and Gulf--and are available at the request of the OSC (40 CFR § 1510.54). The teams either have at their home base, or know where to obtain, the most sophisticated containment, transfer, and clean up equipment available, with cargo aircraft to deliver it (U.S. Coast Guard, no date). Their average response time is four hours.

The Joint Canada-United States Marine Pollution Contingency Plan is designed to establish a response mechanism to pollution incidents that threaten the waters of both nations (U.S. Coast Guard and Can. Marine Transp. Admin. 1974; hereinafter cited as Joint Canada-U.S. Plan). It may also be invoked when one country requires assistance from the other to control a spill with only internal ramifications (Joint Canada-U.S. Plan § 103.2). The Joint Canada-U.S. Plan provides for an OSC, drawn from the nation in which the spill originated, and a Deputy OSC from the other country (Joint Canada-U.S. Plan § 303). The OSC is responsible for coordinating the response efforts of both nations and is assisted by a Joint Response Team made up of both the U.S. and Canadian Regional Response Teams (Joint Canada-U.S. Plan § 302). Costs of the combined operations are to be borne by the country in whose waters the spill occurred.*

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*"Agreement Between the United States of America and Canada on Great Lakes Water Quality," 23 U.S.T. 301, T.I.A.S. No. 7312, Annex 8 (1972).

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TECHNOLOGICAL ISSUES--NORMAL OPERATIONS

SITING OF DRILLING RIG OR VESSEL

Setting Up a Jack-up Drilling Rig and Anchoring a Drilling Vessel

What are the environmental consequences of resuspending bottom sediments and associated contaminants?

Some sediment is disturbed during siting of a jack-up rig or drilling vessel. The amount of sediment resuspended and the extent of the affected area will depend on many factors, including the size and type of rig, lake currents, and the nature of the lake bottom. Placement of drill-ship anchors will disrupt a smaller surface area, though possibly to a greater depth, than the jack-up rig pads.

It is difficult to determine exactly how much bottom area and sediment will be disturbed by a particular drilling rig since this depends on the type of rig and the nature of the bottom. The greatest impact would probably occur when a jack-up rig with large pads is set up on soft, unconsolidated sediments. [Jack-up rigs would not normally be used in areas of Lake Erie where the substrate is soft for a considerable depth, and therefore unstable; in such cases a drill ship would be used (Hurd 1978--personal communication).] Based on the size of rigs currently in service in Canadian waters of Lake Erie, the bottom area disturbed by a jack-up rig would be approximately 650 m^2 (7000 ft^2) (Underwater Gas Developers 1976).

Jack-up drilling rigs are usually towed to the drill site where supportive legs are lowered to the lakebed. Pads at the base of these legs are securely placed on the substrate and the platform is elevated approximately 3-4 m (10-13 ft) above the water surface on legs utilizing the pads for support. When a floating rig is used, it is secured by a multiple anchor arrangement set by service vessels. As noted previously, the Canadian drilling ship Telesis has five 381-m (1250-ft) cables, each of which has two 4100-kg (9000-lb) anchors.

Bottom disruption is of concern not only because of direct destruction or displacement of benthic habitat and associated organisms, but also because of the indirect effects of sediment and contaminant resuspension. Sediments are the principal sinks for heavy metals and other contaminants in lake systems (Fitchko and Hutchinson 1975; Szucs and Krais 1976).

Lake Erie sediments have been shown to contain high levels of trace and minor elements. In particular, antimony (Sb), arsenic (As), Beryllium (Be), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), vanadium (V), and zinc (Zn) have shown enrichment in surficial sediments as a result of recent anthropogenic loadings (Kemp et al. 1976, Kemp and Thomas 1976, Walters et al. 1974) (see Table 3). In addition, iron (Fe),

manganese (Mn), and sulfur (S) may show high concentrations in surficial sediments as a result of migration in interstitial pore waters (Kemp et al. 1976). Organic carbon (C), phosphorus (P), and nitrogen (N) also show enrichment, probably as a result of eutrophication (Kemp and Thomas 1976). Chlorinated hydrocarbon pesticides such as aldrin and DDT are often associated with particulate suspended solids and are incorporated in the sediments when these particles settle out of the water column (Leshniowsky et al. 1970, Pfister et al. 1971).

The degree of contamination of surficial sediments varies widely within Lake Erie. In general, concentrations of pollutants are highest in close proximity to the point of introduction. Regions near industrial centers such as Detroit, Cleveland, and Buffalo exhibit high concentrations of contaminants in sediments. Many open lake areas do not show comparable enrichments (Kemp et al. 1976). Sediments in dredge-spoil disposal areas, since they have been removed from harbors and rivers, also have relatively high concentrations of contaminants compared to other areas of the Lake (Szucs and Krais 1976, Fitchko and Hutchinson 1975). Open lake disposal areas are generally located as close to the harbor as possible without interfering with navigation, recreation, or municipal water intakes (U.S. Army Corps of Engineers 1969) (Figs. 13 and 14).

The sediments of the central and eastern basins of Lake Erie, where drilling, if permitted, would most likely occur, are predominantly post-glacial muds and soft, gray, silty clay (Thomas et al. 1976), with some areas of sand and glacial sediment (see Fig. 3). Generally, the sediments are fine-grained particles (silt- and clay-sized) with a high adsorptive capacity for contaminants; these would remain suspended in the water column longer than larger particles (Leshniowsky et al. 1970, Szucs and Krais 1976).

Potentially the impact with the most far-reaching effect would be resuspension of sediment containing contaminants, since resuspension may reintroduce potentially toxic substances to the water column and enhance their availability to the biota. Resuspension of sediments with low or moderate contamination levels may also be a potential problem for other reasons. For example, habitat disruption in fish spawning areas due to resuspension of sediments could interfere with spawning success and affect populations. Sediment resuspension near municipal water intakes could entrain contaminants in public water supplies and create a health problem or require expensive water purification treatment (see Fig. 13). Impacts from sediment resuspension during siting and drilling should be further considered.

The magnitude of any impact will depend on numerous factors including the amount of sediment that is resuspended and the length of time it remains in the water column, sediment and water chemistry, and rate of dispersal. Since most Lake Erie sediments are fine-grained, and will remain suspended for a long period of time (Kemp et al. 1976, Thomas et al. 1976), they are subject to dispersal by water movement. Mobilization of certain substances, particularly some metals, would be expected to increase under reducing conditions that exist in anoxic regions of the Lake.

Potential problems which might arise as a result of sediment resuspension have been reviewed in the preceding discussion. The actual extent of impacts depends upon many factors and is highly site-specific. Only a quantitative assessment of such factors as resuspension, solubility, and dispersion rates

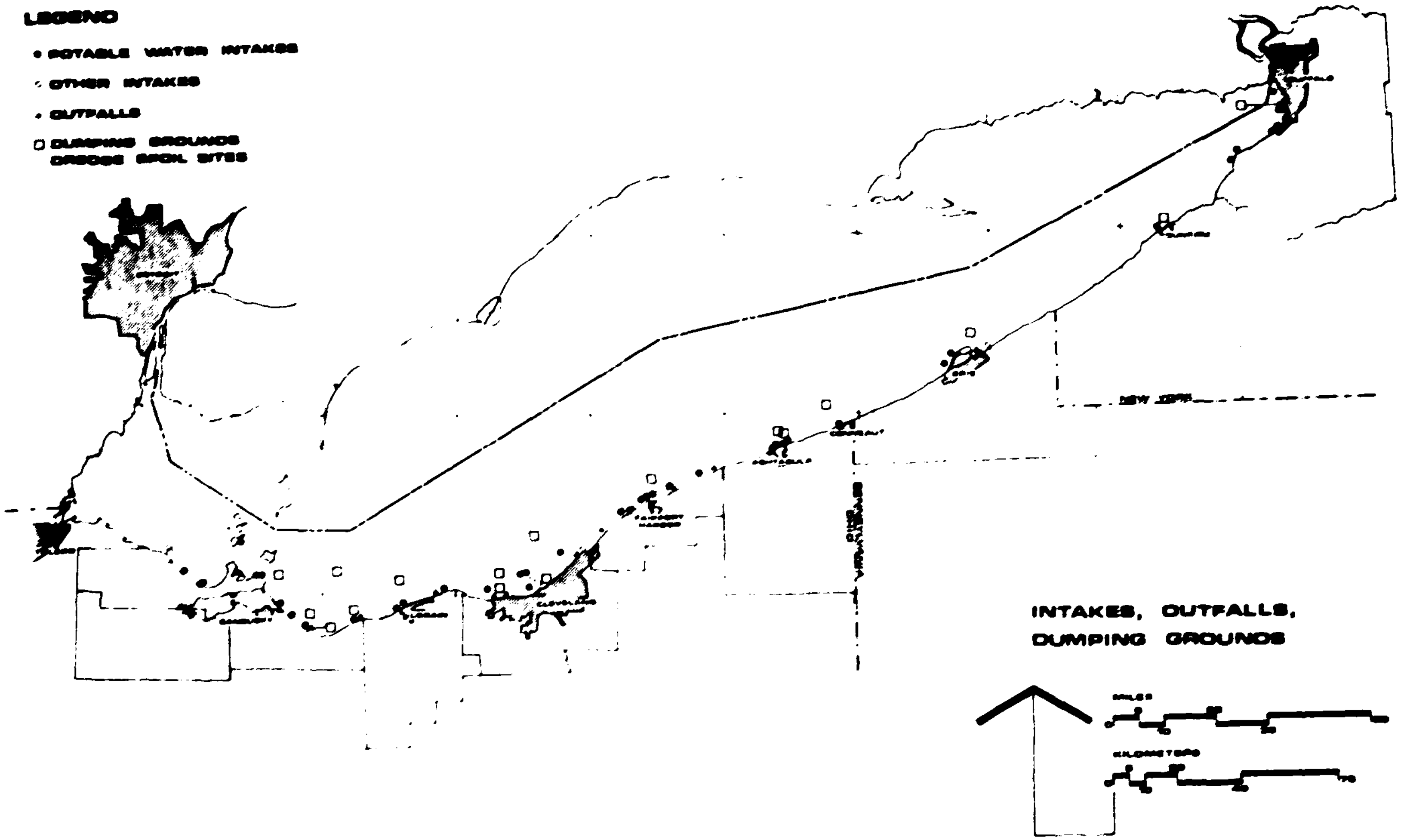
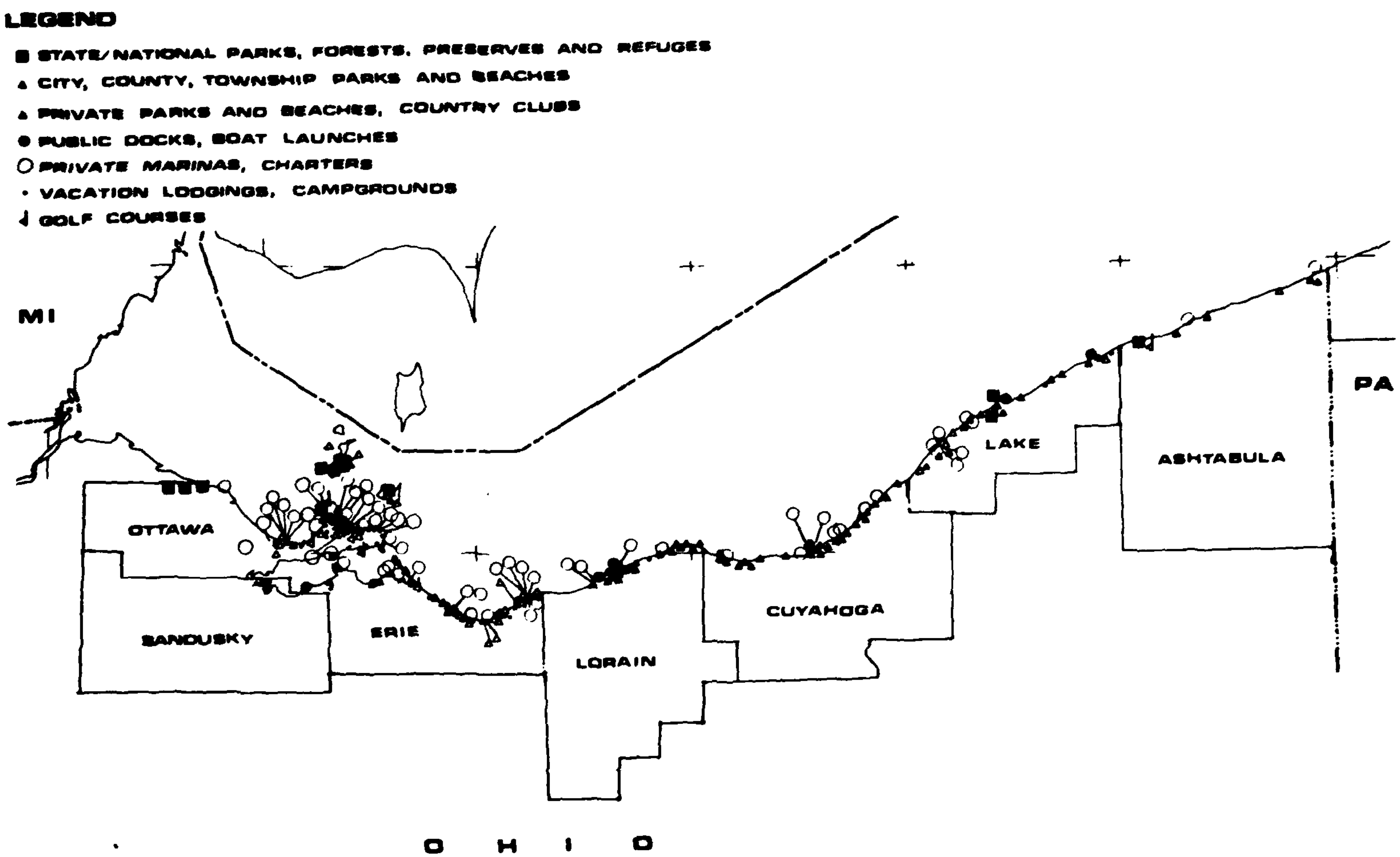


Figure 13. Lake Erie Intakes, Outfalls, and Dumping Grounds. Source: NOAA charts.


LEGEND
STATE/NATIONAL PARKS, FORESTS, PRESERVES AND REFUGES
CITY, COUNTY, TOWNSHIP PARKS AND BEACHES
PRIVATE PARKS AND BEACHES, COUNTRY CLUBS
PUBLIC DOCKS, BOAT LAUNCHES
PRIVATE MARINAS, CHARTERS
VACATION LODGINGS, CAMPGROUNDS
GOLF COURSES
MI
PA
OTTAWA
SANDUSKY
ERIE
LORAIN
CUYAHOGA
LAKE
ASHTABULA
O H I O

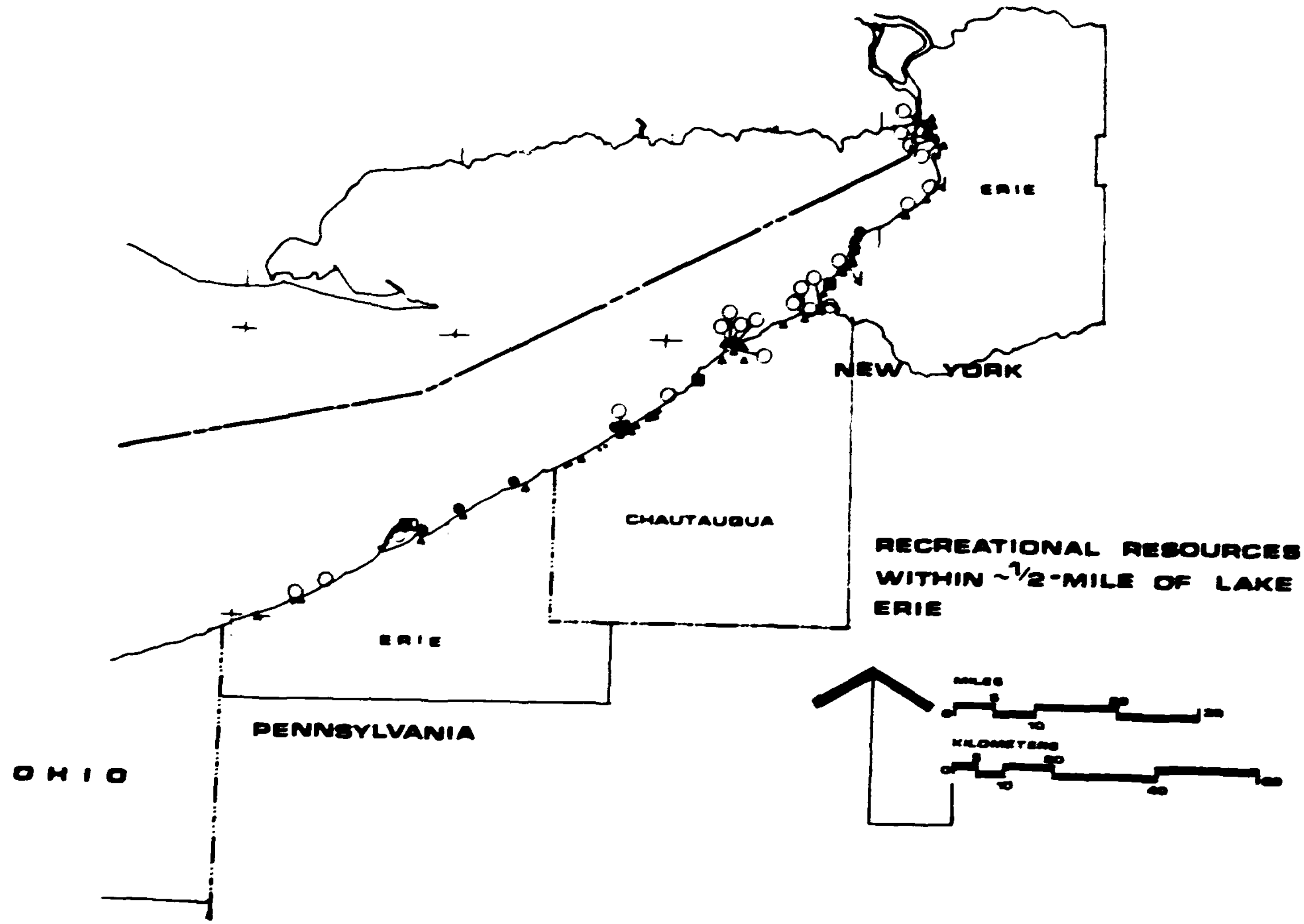


Figure 14. Recreational Resources within One Half Mile of the Shore of Lake Erie.

can indicate the actual level of impact. Impacts from sediment suspension during drilling siting should be considered further.

Obstruction to Navigation by Jack-up Rig or Drilling Ship

What restrictions are there on the siting of drilling platforms in the Lake?

Under the Rivers and Harbors Act of 1899, the Army Corps of Engineers has permitting authority over obstructions in navigable waters (33 USC § 403). In deciding whether to grant the permit, all relevant factors will be considered, including conservation, economics, aesthetics, general environmental concerns, fish and wildlife protection, navigation, recreation, water supply, and water quality [33 CFR § 309.120 (j)(1)(ix)(a); see Cowles 1976]. Under the Coastal Zone Management Act (16 USC § 1451 *et seq*), the permit application would have to receive the approval of any state with an approved CZM plan (16 USC § 1456). In addition, Pennsylvania and New York have complementary legislation requiring permits for obstructions [N.Y. Envir. Conser. Law § 15-0503 (McKinney); 32 Pa. Cons. Stat. Ann. § 681 *et seq* (Purdon)].

Since the land under the Great Lakes is controlled by adjacent states,* each state has the power to design and implement a leasing and drilling program. From the proposed lease in Pennsylvania and from discussions with New York and Ohio officials, it appears that the states will include siting restrictions in their programs. These restrictions might include buffer zones next to state and international boundaries, the shoreline, and municipal water intakes (Pa. Dep. Environ. Resour. 1977a). The states may even limit drilling locations within the lease tract (Pa. Dep. Environ. Resour. 1977a).

SURFACE HOLE DRILLING

Drilling of the Surface Hole Using Open-Cycle Technology

What effect will the discharge of surface hole cuttings have upon the Lake Erie ecosystem?

Once the drill ship or jack-up rig is stationed in position, drilling proceeds. A surface hole is drilled to a depth of at least 15 m** (50 ft) into competent bedrock. The surface hole has a larger diameter than deeper drill holes and is usually 28 cm (11 in.) in diameter (Lawler, Matusky & Skelly 1977). In Canadian waters the drilling is open-cycle, with lake water or bentonite mud used as a drilling fluid to cool the bit, lubricate the drillstem, and carry drill cuttings to the top of the hole, where they are discharged directly to the Lake.

Should closed-cycle drilling be required for the surface hole, a mud would be used as a drilling fluid (see Tables 30 and 31). The drilling mud

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*State title to the beds of navigable internal waters comes from the English Crown for the original thirteen states [Mumford v. Wardwell, 73 U.S. 423, 436 (1867)], and from the "equal footing doctrine" for the remaining states [Pollard's Lessee v. Hagan, 44 U.S. 212 (1845)].

**To a depth of 9.1 m (30 ft) for a drill ship. The surface hole will have a diameter of 37 cm (14.75 in.).

that would be used in most situations is bentonite clay mixed with water to resultant concentrations between 15,000-100,000 μg/mL. Any loss of bentonite would cause a turbidity plume.

Only minor addition of drilling fluids to the Lake is anticipated during closed-cycle drilling of the surface hole because most of the drilling fluid is contained (except for minor losses) within the system (see Technological Issues--Drilling to Depth).

Drilling of the surface hole using an open-cycle system would produce a discharge of water containing drill cuttings. The discharge would be directed upward from the water-lake bottom interface toward the lake surface. The composition of the cuttings depends upon the sediments and other strata encountered. These will include post-glacial sediment, glacial infill, and upper Devonian shales. The materials have very low solubilities (Van Tyne 1977--personal communication) and therefore can be considered chemically inert. In the eastern basin, post-glacial sediment and glacial infill may be up to 26 m (85 ft) and 40 m (131 ft) thick, respectively, and in the central basin between 20 m (66 ft) and 30 m (98 ft) thick (Sly 1976). When the surface hole is cut 15 m (50 ft) into the underlying rock, the maximum quantity of cuttings discharged would be equivalent to a cylindrical volume approximately 89 m (292 ft) long with a radius of 14 cm (5.5 in.), a total discharge of 8.3 m^3 (292 ft^3).* A rotary bit will produce cuttings which range in size from 1 cm (0.39 in.) in diameter down to very fine particles (Lawler, Matusky, & Skelly 1977).

The drilling of the surface hole may be completed in approximately 20 hours (Lawler, Matusky & Skelly 1977). Assuming a constant discharge of cuttings [maximum total volume of 8.3 m^3 (292 ft^3) from the surface hole for the 20-hour period], the discharge rate would be approximately 1.2×10^{-4} m^3/s (4.2×10^{-3} ft^3/s). If the pumping rate of input water used for the drilling is 15.8 L/s (250 gal/min) and this rate is equal to the discharge rate, then the discharge would be relatively concentrated, but of low volume and short duration (i.e., less than one day).

The discharge will form a small turbidity plume near the hole which will elevate total suspended solids above background levels, but the area affected should be small. The larger and denser particles will settle out within a relatively short time whereas the smaller and less dense particles forming the turbidity plume will be carried by prevailing currents, one component of which is the discharge itself. Rochester Gas and Electric Corporation (1975) found dilution factors ranging from 1000:1 to 10,000:1 at a distance of 0.8 km (0.5 mi) during a dispersion study of highly concentrated dye on the south shore of Lake Erie.

Dispersal of the turbidity plume will also depend on the location of the thermocline. When the drill hole is located below the thermocline, a slight density barrier will exist and restrict dispersal of particles into the more biologically active epilimnion. Because the cuttings are primarily chemically inert rock, no additional oxygen demands should result in the hypolimnion except from resuspension of some recent organic sediment.

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*If a drill ship is used, the total discharge will be 5 m^3 (177 ft^3) at a rate of 6.8×10^{-5} m^3/s (2.4×10^{-3} ft^3/s).

Toxicity thresholds of fish to bentonite clay and other largely insoluble materials are high. Logan et al. (1973) found suspended solid concentrations of 10,000 μg/mL for 96-hour tests nontoxic to trout, and Wallen (1951) and Wallen et al. (1957) found concentrations of montmorillonite and five other clays up to 100,000 μg/mL nontoxic to several species of freshwater fishes.

Potential biological impacts from turbidity and particle deposition can be primarily mechanical or physical impacts. Direct effects of suspended solids on fishes occur to the respiratory system. Delicate gill filaments can be abraded and clogged by suspended material, causing an increase in mucous production and interfering with oxygen exchange, thereby producing an increase in metabolic stress (Ellis 1937, 1944; Wallen 1951; Horkel and Pearson 1976). Larval fish may be more susceptible to adverse effects from suspended solids because they lack the ability to shed solids from their gills by mucous secretion (Everhart and Duchrow 1970).

Deposition of suspended solids on the lake bottom may affect benthic invertebrates and hatching success of demersal-attached fish eggs. At levels of 1000 μg/mL yellow perch egg hatching success was significantly reduced (Schubel et al. 1973). Eggs of pelagic spawners, e.g., cisco and lake trout, may also be affected by high concentrations of suspended sediment. If the sedimented material has a chemical or biological oxygen demand, oxygen competition may occur at the water-sediment boundary. This oxygen demand may also cause suffocation of benthic organisms in addition to physical blanketing of the organisms by the sediment. In areas where the lake bottom is a rocky, gravel substrate, sedimenting material may fill the interstices in the substrate thereby reducing the surface area available for benthic colonization (Cordone and Kelley 1961). This may lead to a reduction in density of benthic invertebrates and a loss of fish prey availability.

The discharge of surface hole cuttings into the Lake has been identified as an environmental issue. The discharge should be evaluated in terms of its magnitude and importance for being a source of environmental impact and placed in perspective. As a source of impact, the discharge of surface cuttings from a single well is relatively small. The duration of the discharge is less than one day; the maximum amount of material is small, i.e., 8.3 m^3 (292 ft^3), and the discharge is composed primarily of chemically inert, nontoxic material. For these reasons certain environmental issues, such as biomagnification of toxins and synergism of toxic materials, can probably be eliminated from consideration.

However, the physical effects of introduced suspended solids on the biota found near the drilling rig must be considered. Although fishes are unaffected by natural turbidity levels, excessively high turbidity experienced over long periods of time can affect fish (Everhart and Duchrow 1970). Concentrations may be high close to the discharge point; exposure time is still unknown. In addition, when adding potential exposures the mobility of fishes must be considered. Subjected to a condition of temperature or water quality that is undesirable, fish can and will actively seek a preferable environment. Although impacts to fish eggs and larvae may occur, the area affected and the duration of exposure may preclude a measurable effect. Insufficient information is presently available to evaluate the impacts of high suspended solid concentrations on phytoplankton and of sediment deposition on benthic communities.

On a lakewide basis, the effect of an entire season of well drilling must be evaluated. It is assumed that: (1) there will be ten drill rigs operating on Lake Erie, (2) each rig can complete a well in two weeks, and (3) the drilling season begins in April and ends in September. With these assumptions, the total number of complete wells drilled per season would be 130. If another 20 wells are added to account for drilling time gained by incomplete drilling or finishing of wells plugged as dry holes or for other reasons, the total becomes 150. The total sediment load to the Lake from drilling 150 surface holes would be 150 wells × 8.3 m^3 (292 ft^3) cuttings per well which equal 1245 m^3 (4.4×10^4 ft^3)* of sediment. One cubic meter of fine sediment, primarily silt and clay-sized particles, weighs approximately one metric ton (Kemp et al. 1977). Therefore, the total seasonal sediment input from surface hole drilling is approximately 1245 metric tons. For comparison, the estimated yearly input of clay and silt-sized particles from shoreline erosion is 7.9 million metric tons, from river inputs 4.1 million metric tons, and from dredged spoils 1.4 million metric tons (Kemp et al. 1977). The sediment loading from drilling would be less than 0.009% of the total loading from dredge spoils, rivers, and shoreline erosion.

CASING PLACEMENT AND SECUREMENT

Cementing the Casing to the Drill-Hole Bore or Sealing the Hole Prior to Abandonment

What effect does the addition of cement for setting of casing or well abandonment have on the Lake Erie ecosystem?

After the surface hole is drilled, a steel casing is set in the wellbore. Drilling to depth resumes after the surface casing is placed and secured. The casing process is repeated for the wellbore between the surface casing and bottom of the hole when total depth is reached. During each step, cement is used to lock the well casings in place and to prevent migration of materials from the surrounding formations into the hole or Lake. Abandonment operations for dry holes, significant oil producers, or retired production wells also requires the use of cement to block the vertical flow of liquids and gases that might otherwise gain access to the abandoned pipe. During casing securement and abandonment operations, excess cement is routinely used to ensure adequate bonding suggesting that some quantity of cement will, in effect, be discharged to the Lake. Specifically, when fluid cement is pumped into a hole for either positioning of casing or well plugging, excess fluid cement may overflow the casing and aggregate on the lakebed surrounding the hole.

Discharge of cement to the lake is an environmental consideration because (1) it is an addition to the Lake, (2) the excess cement used will affect the lake bottom around the drill hole, and (3) some quantity of cement is subject to dissolution during and following the 8-hour setting period (Lawler, Matusky & Skelly 1977).

The composition of cement (Table 36) is primarily calcium silicates (approximately 70% by weight). The specific gravity of cement is greater than

*For a drill ship the total sediment load would be 743 m^3 (2.6×10^4 ft^3).

Table 36. Composition of Type III Portland Cement[a]

Component	Percent Composition by Weight[b]
Tricalcium silicate (3 $CaO \cdot SiO_3$)	56.0
Dicalcium silicate (2 $CaO \cdot SiO_2$)	15.0
Tricalcium aluminate (3 $CaO \cdot Al_2O_3$)	12.0
Tetracalcium alumino-ferrite (4 $CaO \cdot Al_2O_3 \cdot Fe_2O_3$)	8.0
Calcium sulfate ($CaSO_4$)	3.9
Magnesium oxide (MgO)	2.6
Free calcium oxide (CaO)	1.3
Ignition Loss	1.0

[a]Data from Concreter Manual, 7th ed., U.S. Department of the Interior, Bureau of Reclamation.

[b]Due to rounding of figures, total equals less than 100%.

water; therefore any excess cement discharged to the Lake should rapidly sink to the bottom.

According to Lawler, Matusky & Skelly Engineers (1977), approximately 2270 kg (5000 lb) of excess cement is used during surface-casing cementing. For two most conservative analyses, this entire amount could either (1) remain as a solid layer on the lake bottom or (2) dissolve in the water and disperse outward from the drill hole.

In the first case, a layer of cement would be formed on the lake bottom, the size of which would depend on physical factors such as bottom topography (including the shape and size of the built-up pile of drill cuttings), substrate consistency (loose sediments, hardpan rock, etc.), and any bottom currents. This excess cement could form a layer of approximately 5.7 m^3 (200 ft^3), or cover an area 3 m by 3 m (10 ft by 10 ft) to a depth of 0.6 m (2 ft). On solid bedrock substrate, the loss of benthic habitat would be an area on the order of 9.3 to 37.2 m^2 (100 to 400 ft^2). Impacts from loss of benthic organisms and habitat would be minor and temporary. The cement mass would replace the original substrate and function in a manner similar to a hard, irregular surface which could be colonized by some species of attached benthos.

On loose unconsolidated sediment, the cement slurry would tend tq sink into the sediment, possibly being engulfed; it would also extend laterally, but to a lesser distance than on a solid substrate. Because burrowing benthic epifauna are unable to utilize the cement as habitat, localized populations of those organisms would be displaced; however, recolonization by attached forms

would probably occur rapidly once drilling was completed and the rig moved. Displacement of loose sediment by the cement may cause some resuspension, but the magnitude of potential impacts from this resuspension is considered minor. Placement of jack-up pads will disturb a much larger area of lake bottom, approximately 650 m^2 (7000 ft^2) compared to the area disturbed by cementing.

In the alternative case, it is assumed that all the excess cement dissolves. Dissolution of approximately 2270 kg (5000 lb) of cement will contribute approximately 1000 kg (2200 lb) of calcium and 230 kg (505 lb) of silica to the water column in either elemental form or as oxides.

The environmental consequences of cement additions to Lake Erie should be minimal. Cement has been used for years as a structural material in the construction of wharfs, breakwaters, and other shoreline facilities. Colonization of cement substrates by various biota, periphyton, and invertebrates will further minimize any loss of habitat or productivity.

The potential for environmental impact to occur from the use of cement during any phase of gas drilling in Lake Erie is considered minute.

Will states have the authority to oversee offshore casing programs in Lake Erie?

The states have the power to regulate all elements of drilling operations in any manner they choose. Restrictions governing placement of casing pipe, casing securement through cementing, and pressure testing of the cement bond could be written into the lease or enacted in regulations.

DRILLING TO DEPTH

Drilling to Depth Using Closed-Cycle Technology

During closed-cycle drilling, what is the potential for pollution of the Lake and degradation of water quality from contaminants such as salt, brine, hydrocarbons, sulfur compounds, drilling muds, and mud additives? What effects would such water quality degradation have on the aquatic biota of the Lake?

Closed-cycle drilling differs from open-cycle drilling in several respects. In a closed cycle, drilling mud composed primarily of calcium chloride, bentonite clay, and water is used to cool and lubricate the drill bit and remove cuttings. Muds may also contain compounds that provide special gel strength, fill interstices in surrounding formations, and prevent leakage from surrounding formations into the wellbore. Returning muds and cuttings are passed through a shale shaker to remove large drill-cutting particles that are then discharged below the surface of the Lake. The mud is retained and recycled to the mud tanks for reuse. The only discharges during closed-cycle drilling are large cuttings (with some adhering muds) and occasional spillage of a small quantity of mud [approximately 3.8 L (1 gal)] when each new 9.1 m (30 ft) section of pipe is added to the drill string. (For an in-depth discussion of closed-cycle drilling, see the Technological Overview.)

Drilling muds currently used by Canadian drilling operators consist primarily of bentonite clay and calcium chloride in water; however, several types of drilling mud additives may be used when special conditions occur (see Table 30). Although drilling fluids are recycled and not discharged in closed-cycle drilling, some muds and contaminants from the wellbore may reach the Lake when adsorbed to the larger drill-cutting particles that are discharged from the shale shaker.

In sufficient concentrations, many contaminants from the drill hole can be toxic to aquatic biota. Although the study by Neil (1958) does not specifically state that closed-cycle drilling was being used at any of the wells he investigated in Lakes Erie and St. Clair, he did document high concentrations of chlorides, sulfates, sulfides, and phenols in the discharge. When water samples from below the rig and 30 m (100 ft) from the rig were examined, chloride concentrations had dropped from 51,000 μg/mL (as Cl^-) in the discharge to 20 μg/mL at the other two stations. Likewise, sulfates (as SO_4^{-2}), sulfides (as H_2S), and hydrocarbons (as phenol equivalents), dropped from 16,800 μg/mL, 31 μg/mL, and 34 μg/mL, to 55 μg/mL, 0 μg/mL, and 2-3 μg/mL, respectively. These concentrations are well below the toxic threshold levels of most aquatic biota (USEPA 1976). Although these concentrations are below the toxic threshold of most aquatic biota, appropriate available treatment technology will be required for the discharge of drilling wastes. In addition, water quality standards for New York, Pennsylvania, and Ohio (see Table 26) will be considered when addressing discharge limitations. IJC objectives (IJC 1977, 1978) will also be considered. Chloride toxicity is caused by the associated metallic cations (Doudoroff and Katz 1953) and toxic threshold levels for several species of freshwater fish range from 4900 μg/mL to 12,700 μg/mL (Clemens and Jones 1954, Wood 1957). Sulfate toxicity levels for freshwater biota are high. Approximately 95 percent of the waters in the United States that support good fish life contain sulfates at concentrations up to 90 μg/mL (Becker and Thatcher 1973). Sulfide, alternatively, is quite toxic even at low concentrations when present as H_2S. Thus the discharge may present a graded concentration plume in which conditions may be toxic at the discharge and nontoxic a short distance away.

Discharges of drill cuttings during closed-cycle drilling may also include small amounts of drilling muds and mud additives that are adsorbed to the particles. During closed-cycle drilling, a new drill pipe must be installed every 9.1 m (30 ft). During this operation approximately 3.8 L (1.0 gal) of drilling mud is spilled and eventually washed into the water from the platform. For a 610-m (2000-ft) well, half of which is drilled closed-cycle, this results in about 130 L (35 gal) of discharged drilling mud and additives. Lawler, Matusky & Skelly (1977) estimated that this and other losses would result in a discharge of about 18 L (4.8 gal) of drilling fluids per hour. This amounts to 2 percent of the natural flux of calcium or chloride past the rig through a vertical section 3 m (10 ft) wide and 15.2 m (50 ft) deep with a lake current of 3 cm/s (1.2 in./s). The amount of material discharged in this manner is small, and the biological effects of such discharges assumed to be minor because the major components of drilling muds, clays and salts (see Table 31), are only toxic at high concentrations, generally above 1000 μg/mL (Ray 1978, Land 1974, Falk and Lawrence 1973) will be researched in greater detail in Phase II.

Polybrine drilling mud (see Table 31) has a pH of 10.0-10.5 and barite mud, which contains caustic soda, has a pH of 9.5-10.0. Although the pH of both muds is relatively high, the amount of discharge is small. Dilution in the Lake should rapidly reduce pH to ambient levels.

The chromium compounds used as drill fluid additives contain the element in two chemical forms, trivalent and hexavalent. Toxicity levels of trivalent chromium, usually contained as a salt, range from approximately 5 µg/mL in soft water to 80 µg/mL in hard water (Land 1974, Becker and Thatcher 1973). Hexavalent chromium is usually combined with lignosulfonates (fluid additive). Chromate and dichromate toxicity levels for fish are variable, but the majority reported are on the order of 100 µg/mL. Although the short-term toxicity of chromium is relatively high, time of exposure is an important factor. Exposures for longer periods, e.g., weeks, reduces the level that causes biological harm by two orders of magnitude. Chronic exposure, which is not likely from a drilling operation lasting approximately two weeks, reduces toxic thresholds to the order of tenths of µg/mL.

Besides the loss of drilling muds and inorganic and organic additives, other materials such as oils and lubricants associated with the operation of machinery may be lost during normal operations.

As previously stated, the loss of drilling fluids during normal operations represents an emission rate of about 18 L/hr (4.8 gal/hr). Since the total drilling time is approximately 75 hours (Hurd and Kingston 1978), this represents a short-term release.

Since the threshold concentrations for toxicity of some chemical elements and ions are low [e.g., chromium = 100 µg/mL (EPA 1976)], drill mud additives may contain components that could be considered toxic; however, no records of any fish kills associated with normal operational discharges were found in the literature. At present there is insufficient data to assess the environmental impact of the discharge of cuttings and contaminants from closed-cycle drilling.

The release of gases and liquid hydrocarbons (C_6-C_{16}) to the Lake may occur during normal drilling operations. Because of the already high levels of dissolved methane in Lake Erie (Howard et al. 1971) and the relatively large biogenic emission rates (Frea et al. 1977) from bottom sediments, it is assumed that this gas will present almost no water quality problem. However, the biological oxidation of methane may provide an additional oxygen demand stress on hypolimnetic waters; compared with other sources of oxygen demand, it is expected that this would be insignificant.

The composition of gases from 37 wells operating in Lake Erie is shown on Table 37. Values for hydrogen sulfide could only be calculated for 4 of 37 wells.

The composition of the hexane-plus fraction (a gas fraction that includes hexane and other gases up to approximately C_{19}), comprising approximately 0.03 percent of the total volume, is unknown. Because no data identifying the compounds of the hexane-plus fractions in Lake Erie natural gas were found, OCS literature sources were examined. Data were provided by Brooks et al. (1978) for a recent gas blowout on the OCS in the Gulf of Mexico. Thirty-eight

Table 37. Composition of Gases from 37 Wells

Component	Mean (%)	Range (%)
Methane	89.90	84.0-90.7
Ethane	4.72	1.19-7.74
Propane	1.28	0.21-2.36
Hydrogen sulfide	0.56	0.41-0.72
Iso-butane	0.28	0.03-0.90
n-butane	0.27	0.03-0.49
Iso-pentane	0.05	0.01-0.12
n-pentane	0.04	0.01-0.09
Hexane-plus	0.03	0.01-0.23

Source: Ont. Dep. Mines and Northern Affairs (1970).

compounds in the C_6-C_{11} range were identified. Aromatics and liquid n-alkanes (with the exception of n-pentane and traces of n-hexane) were not detected in the seep gas phase. The total concentration of C_6-C_{14} hydrocarbons was about 1.23 µg/mL of gas (Brooks et al. 1978). Dissolved hydrocarbons (C_6-C_{14}) from six samples collected over the plume indicated an unresolved complex mixture beginning around n-nonane. Concentrations for the unresolved compounds were 0.9-18.7 µg/mL, and mass spectrum fragmentation suggested substituted cycloalkanes and cycloalkenes. This indicated that few of the lower-molecular-weight liquid hydrocarbons partitioned into the water phase while most of the higher-molecular-weight liquid hydrocarbons and the aromatics rapidly dissolved and were not present in the seep gas phase. However, this is not in agreement with solubility calculations (e.g., McAullife 1966); therefore, an alternate source, such as the resuspension of bottom sediments (concentrations ranged from 3.3 to 32.5 µg/mL), would be needed for the higher-molecular-weight components.

The light gaseous hydrocarbons (C_1-C_4) are not toxic to biota, while the light liquid aromatics (e.g., benzene, toluene, and xylene) are considered to be the more toxic components of petroleum (Brooks 1975). However, different results were reported during an NSF (1974) workshop, where it was shown that the aliphatic hydrocarbons depressed the photosynthetic rate considerably more than did the aromatics at similar concentrations. An increase in toxicity relating to greater substitution on the benzene ring was also found with both mixed ocean cultures and *Skeletonema costatum* unialgal cultures. Levels as low as 0.005 µg/mL decane and 0.02 µg/mL octane resulted in a 50 percent reduction in photosynthesis; similar reductions were observed for aromatics (the lowest concentrations were 3 µg/mL for xylene and toluene), yet toxic levels were much higher than for the aliphatics (NSF 1974).

Effects of Drilling and Gas Production on Potable Water Supplies

What is the potential impact of drilling activities on the potable water supply?

Because Lake Erie is used by numerous municipalities as a source of potable water, the impact of gas drilling activities on these water supplies must be assessed with respect to both normal drilling and production operations and accidents.

Present operations in the Canadian waters of Lake Erie result in losses of some materials to the overlying water column during drilling and well stimulation. In addition to platform drainage of drilling muds and lubricating fluids during the drilling operation, losses of material to the water column presently occur during siting of the drilling rig or vessel and well stimulation. After conducting water surveys, the Ontario Water Resources Commission "*concluded that the offshore gas drilling industry in Lake Erie does not contribute a source of significant water pollution.... and the discharge of spent fluids (fracturing additives) to the Lake should not impair lake waters for other reasonable uses*" (Borodczak 1968). However, analyses for BOD (biological oxygen demand), COD (chemical oxygen demand), ABS (anionic detergents), nitrogen and phosphorus compounds, phenols, sulfur, and laboratory pH do not, in themselves, provide sufficient information to assess the potential impact of these wastes on the Lake during drilling operations. Additional chemical and biological data need to be examined with respect to the impact on potable water supplies, e.g., magnitude and chemical composition of these wastes; near field dilution; possible losses to the biota, sediments, or atmosphere; oxidation and biodegradation; and potential technology for treatment or removal (see p. 147).

Some losses of natural gases to the water column during the drilling and well stimulation periods are expected. With the exception of methane, there seems to be no historical information on low-molecular weight hydrocarbons in Lake Erie. Reported concentrations of methane in the western basin of Lake Erie, near South Bass Island, ranged from 7-27 μg/mL at a depth of 1 m (3.3 ft) to 41-51 μg/mL near the bottom at 4 m (13 ft) (Howard et al. 1971). Since the water column temperature was 25°C, this was close to two times saturation (Table 38). For a eutrophic shield lake near Winnipeg, Canada, the methane evasion rate (diffusion to the atmosphere) was calculated to be 5.4 mg/m^2 lake surface per day during summer stratification and 120 mg/m^2 per day (highly variable between 16-370 mg/m^2 per day) during fall overturn (Rudd and Hamilton 1978). Methane concentrations were slightly lower in the water column of this lake (3 μg/mL at 5 m to 8-11 μg/mL at 8 m) than those of Lake Erie even though loss from the bottom sediments (176 mg/m^2 sediment per day were similar to those reported for one measurement in Hamilton Harbor, Ontario (160 mg/m^2/day) (Chau et al. 1977). However, processes within Hamilton Harbor (Polak and Haffner 1978) are probably not representative of the open waters of Lake Erie. Methane oxidation and conversion into CO_2 and bacterial cell material must also be taken into account (Rudd and Hamilton 1978). However, it is suspected that release of methane to the Lake by drilling and well stimulation operations may not significantly add to the background levels already present in the water column. Any release would be rapidly lost to the atmosphere since methane is insoluble in water.

Table 38. Solubility of Some C_1 to C_4 Hydrocarbons in Water at Four Temperatures: Data Calculated from Mole Fractions at Total Pressure of 1 atm[a]

Hydrocarbon	Formula	Solubility (mg/kg) 0°	10°	20°	30°
Methane	CH_4	41	31	25	20
Ethane	C_2H_6	134	89	64	49
Ethene (ethylene)	C_2H_4	-	190	149	120
Ethyne (acetylene)	C_2H_2	2030	1524	1197	978
Propane	C_3H_8	181	113	78	57
Propene	C_3H_6	-	-	377	257
Propyne	C_3H_4	6718	4168	3068	2472
cis-Propene	C_3H_6			527	437
n-butane	C_4H_{10}	221	131	85	60
Isobutane	C_4H_{10}	101	74	55	40
2-Methyl-Propene	C_4H_8	908	567	381	272

[a]Data from Wilhelm et al. (1977).

From analyses of 37 producing wells in the Lake, the average concentrations of various components were found to be: 89.9% methane, 4.72% ethane, 1.28% propane, 0.28% iso-butane, 0.27% n-butane, 0.05% iso-pentane, 0.04% n-pentane, 0.03% hexane-plus hydrocarbons, and (for only 4 of the 37 wells) 0.56% hydrogen sulfide (Ont. Dep. Mines and Northern Affairs 1970). The range for the hexane-plus hydrocarbon fraction is 0.01 to 0.23 percent. Even though the composition of underwater vented gas in the outer continental shelf region of the Gulf of Mexico is slightly more concentrated in the C_2-C_5 region [ranging from 7% ethane to 0.6% iso- and n-pentane (Brooks et al. 1977)], it was estimated that 0.1 percent of the vented gas was composed of C_5-C_{10} hydrocarbons with an average molecular weight of 86 (corresponding to C_6). This liquid hydrocarbon fraction is a relatively complex mixture containing compounds as high as C_{15} (Brooks et al. 1977) which can inhibit primary productivity (Brooks 1975). Because the aromatics are more soluble than the normal paraffins (McAuliffe 1966), it is suspected that these would remain longest in the water column. Although Brown and Huffman (1976) reported losses of aromatics from open ocean waters, with a decrease in persistence of cycloparaffin, isoparaffin, and finally aromatics, a recent report indicated that 60-92 percent of the total hydrocarbons in the open surface waters of the Gulf of Mexico were composed of aromatics (Sauer et al. in press). These aromatics

were benzene (9.3-101 nL/L), toluene (4.5-376 nL/L), ethyl-benzene (0.4-4.5 nL/L), m- and p-xylene (2.7-24.4 nL/L), o-xylene (0.3-10.1 nL/L), methyl-cyclohexane (0.4-6.9 nL/L), and total aromatics (33.2-448 nL/L). Elevated concentrations of hydrocarbons in potable water supplies may present a health hazard. Benzene is listed in the Category I OSHA tentative carcinogen list (Anon. 1978). Benzene, toluene, and the o-, m-, and p-xylenes were measured in District of Columbia tap water (Saunders et al. 1975), and all of the above compounds, with the exception of methyl-cyclohexane, were identified in U.S. drinking water (USEPA 1975). Benzene, xylene, and other organic compounds were also identified in the Cleveland, Ohio, drinking water supply (Sanjivamurthy 1978).

The release of the 0.03 percent hexane-plus fraction to the water column from natural gas losses to Lake Erie thus represents a concern since some of these compounds are highly soluble, possibly carcinogenic, and impart a taste and odor to water. These compounds could elevate concentrations above normal background levels presently in the Lake and thus have an impact upon potable waters. Chlorination of these hydrocarbons would compound the issue because of the production of as yet unknown halogenated products.

Water Purification

What procedures do water purification facilities currently use for treatment of Lake Erie water? Would these procedures, or other readily available ones, be adequate for treatment of potential contaminants associated with offshore drilling for natural gas?

To determine water treatment methods currently in use, six locations using Lake Erie for their water supply were selected. As shown in Table 39, all of the purification facilities in these locations employ convential water treatment processes for surface water. These treatments are chlorination, coagulation, flocculation, clarification, and filtration. Each facility uses alum ($Al_2(SO_4)_3 \cdot 14H_2O$) as the coagulant. Five of the locations use activated carbon for taste and odor removal. Other treatments include fluoridation (to prevent dental cavities) and using caustic soda or lime for pH adjustment.

With treatment technologies fully developed and readily available, it is possible to remove or reduce the concentrations of many of the contaminants associated with offshore natural gas drilling activities. Current procedures used by selected water purification facilities are presented in Table 40.

Adsorption on activated carbon is generally used for removal of organics. Reduction of phenol concentrations is accomplished by an oxidation process using chlorine dioxide or potassium permanganate, or by adsorption onto activated carbon.

Hydrogen sulfide, which produces an objectionable odor, can be rapidly oxidized to sulfate with the use of chlorine. Other sulfur components can be controlled by adsorption onto activated carbon or through precipitation with alum.

High levels of turbidity (clays) encountered at the purification facilities are treated by adjusting the dosage of coagulant.

Table 39. Physical and Chemical Procedures Currently Used by Selected Water Purification Facilities for Treatment of Lake Erie Water[a]

Procedure	Sandusky, Ohio	Lorain, Ohio	Cleveland, Ohio	Ashtabula, Ohio	Erie, Pa.	Buffalo, N.Y.
Disinfection/ oxidation	Chlorine	Chlorine	Chlorine/ potassium permanganate	Chlorine	Chlorine	Chlorine
Coagulation	Alum	Alum	Alum or lime	Alum	Alum	Alum
Adsorption	None	Activated carbon, powdered	Activated carbon	Activated carbon	Activated carbon	Activated carbon
Filtration	Sand[b]	Activated carbon, granular	Sand	Sand	Sand	Sand and anthracite
pH adjustment	Caustic soda	Lime	Lime	-	-	-
Auxiliary chemicals	-	Fluoridation	Fluoridation	Fluoridation	-	-

[a]Data obtained by personal communication (1978) as follows: D. Walshuch (Sandusky, Ohio); R. Jaworski (Lorain, Ohio); J. Jefferies (Cleveland, Ohio); N. Pizzi (Ashtabula, Ohio); N. Jacquel (Erie, Pennsylvania); R. O'Connor (Buffalo, New York).

[b]Sand and anthracite (dual media) will be used in 1979.

Table 40. Physical and Chemical Procedures Onsite or Readily Available to Water Purification Facilities on Lake Erie for Treatment of Contaminants Associated with Offshore Natural Gas Drilling Activities[a]

	Procedure					
Contaminant	Sandusky, Ohio	Lorain, Ohio	Cleveland, Ohio	Ashtabula, Ohio	Erie, Pa.	Buffalo, N.Y.
Organics	None	Adsorption on activated carbon	None	Adsorption on activated carbon	Adsorption on activated carbon	None
Phenol	None	Chlorine dioxide	None	Chlorine dioxide	Activated carbon or potassium permanganate	None
Sulfur compounds	Oxidation with chlorine	None	Oxidation with chlorine	Oxidation with chlorine	Activated carbon	Precipitation with alum
Heavy metals	Coagulation with alum	Coagulation with alum	Coagulation with alum	Coagulation with alum	None	Coagulation with alum
Clays (turbidity)	Coagulation with alum	Coagulation with alum	Coagulation with alum	Coagulation with alum	Coagulation with alum	Coagulation with alum
HCl (low pH)	None	Lime	None	None	Lime or caustic soda	None
Total dissolved solids	None	None	None	None	None	None

[a]Data obtained by personal communication (1978) (see footnote to Table 39).

Heavy metals are treated at the selected facilities only if they are in suspended form; the metals can then be removed by coagulation. Activated carbon may also be helpful in reducing dissolved metal concentrations; its use has resulted in fairly good removal efficiencies at neutral or high pH (Sigworth and Smith 1972; Dean et al. 1972; Culp et al. 1978).

Because Lake Erie is highly buffered, the purification facilities contacted did not consider treatment for low pH conditions necessary. But if an acid spill were to occur at the intake, pH adjustment could be made by adding lime or caustic soda.

There is no treatment available at the selected purification facilities for control of total dissolved solids. Any increase in total dissolved solids caused by drilling activities would thus be passed through the facilities untreated [personal communications (1978) with Walshuch, Jaworski, Jefferies, Pizzi, Jacquel, and O'Connor].

To date no hydrocarbon spills with adverse effects on the water supply for any of the selected purification facilities have been reported for Lake Erie. However, analysis of the Cleveland water supply for organic contaminants showed the presence of from 21 to 36 compounds (Sanjivamurthy 1978). This suggests that hydrocarbon contamination is entering the Lake from spills and other unknown sources. An emergency intake/discharge system whereby contaminated water could be discharged into a bay before reaching the plant is available at the Sandusky, Ohio, facility (Walshuch 1978--personal communication).

Based upon present knowledge of chemical components discharged from offshore drilling operations, all reviewed purification facilities are prepared to handle mishaps that might affect their water supply. However, additional data on discharge characteristics is necessary to more adequately assess water treatment capabilities. The staff at the treatment facilities expressed a need for the development of standardized procedures by drilling operators to be used in the event a mishap releasing unacceptable levels of contaminants to offshore drilling activities occurs.

Release of Gas and Diesel Emissions during Drilling

What will be the impact of gases released during drilling and testing?

Diesel emissions from drilling operations would be released to the atmosphere. Engines used on drilling rigs are similar in size to those used by ships on Lake Erie. The addition of diesel emissions from drilling, listed in Table 41, would be small and insignificant when compared to present emissions from ship traffic. Concentrations resulting from these emissions, along with applicable state and federal standards, are given in Table 42.

Table 41. Emissions from Diesel Engines[a]

Pollutant	Emissions, lb/day[b]
Particulates	5.3
Sulfur oxides	11.0
Carbon monoxide	91.8
Hydrocarbons	15.1
Nitrogen oxides	151.0
Aldehydes	1.2
Organic acids	1.2

[a]Data from USEPA (1973).

[b]Based on 24-hr workday, 17 gal/hr consumption. To convert lb to kg, multiply by 0.454.

Table 42. Ground-level Concentrations of Pollutants Due to Diesel Emmission

	Concentration ($\mu g/m^3$)				
Pollutant	1000 m Downwind[a]	Federal Standard[b]	Ohio Standard[c]	Pennsylvania Standard[c]	New York Standard[c]
Particulates	6	260[d]	150[d]	260[d]	80[h]
Sulfur oxides	12	365[d]	260[d]	365[d]	260[d]
Carbon monoxide	96	10,000[e]	10,000[e]	10,000[e]	10,000[e]
Hydrocarbons	16	160[f]	126[f]	160[f]	160[f]
Nitrogen oxides	160	100[g]	100[g]	100[g]	100[g]
Aldehydes	1	n.s.[i]	n.s.[i]	n.s.[i]	n.s.[i]
Organic acids	1	n.s.[i]	n.s.[i]	n.s.[i]	n.s.[i]

[a]Calculated using the emissions from Table 41 and Gaussian dispersion model.

[b]Source: 40 CFR § 50.7G.

[c]Source: Environment Reporter; ER-State Air Laws, The Bureau of National Affairs, Inc., Washington, D.C., 1978.

[d]24-hr standard, not to be exceeded more than once per year.

[e]8-hr standard, not to be exceeded more than once per year.

[f]3-hr (6-9 a.m.) standard, not to be exceeded more than once per year.

[g]Annual arithmetic mean, not directly applicable to short-term releases due to drilling operation.

[h]30-day standard, arithmetic mean of 30 consecutive 24-hr average concentrations.

[i]No standard.

WELL STIMULATION

Fracturing the Gas-Bearing Strata to Increase Gas Flow

What effect will discharge of spent well-fracturing material have on Lake Erie water quality and aquatic biota?

After the well has been drilled to the gas-bearing strata, it may be necessary to artificially stimulate gas flow through the surrounding formations into the wellbore. Two well stimulation processes are routinely used depending on the lithologic characteristics of the production strata. If the production zone is located in limestone, hydrochloric acid is forced into the formation to dissolve the rock and create porous channels through which the gas may flow. In sandstone formations, stimulation of gas flow requires physical fracturing. This fracturing process is accomplished by pumping water, acid, sand, surfactants, nitrogen or carbon dioxide, and occasionally other materials into the formation under pressure.

When pump pressure is discontinued, materials forced into the formation through either process return to the stimulation barge. Well-stimulation fluids are separated from gas returns and stored in tankage on board the barge. Gases are vented to the atmosphere to minimize the potential for an explosion that could be caused by containment of increasing amounts of produced methane on board the barge. This process continues until the rate of return reaches 0.63 L/s (10 gal/min) (Hurd and Kingston 1978). At this time, the barge disconnects its collection lines and allows the small volumes of liquids and gases to return to the water column. It is not economical to continually collect the low volume backflow beyond the 0.63 L/s (10 gal/min) flow rate. After most of the stimulation liquids have returned from the well, it is valved off to await hook-up to a collection line.

Recaptured fluid returns amount to approximately 40-50 percent of the introduced material. The remainder is lost to the formation or the Lake, or is later separated from produced gas at a compressor station.

The Ontario Water Resources Commission, Division of Industrial Wastes, conducted a bioassay on the environmental effects of gas well fracturing on fish (Borodczak 1968). Results of the bioassays on fathead minnows and pearl dace are given in Table 43. Howco suds, Morflow II, Hai-50, and Pen-5 were all considered to be acutely toxic. The report recommended that these materials not be discharged to the Lake. The additives Wac-8 and Wac-10 were considered nontoxic. Although the trade names of the compounds presently used in fracturing on Lake Erie are the same, the chemical composition may have changed between the writing of the Borodczak report and the present time.

The results of these bioassays indicate a potential for toxic conditions to occur. They do not indicate that toxic conditions will occur. The Canadian report concludes that dilution of the discharge would reduce concentrations to nondeleterious levels. A potential weakness is apparent in the design of the bioassays used in the report. Experiments were conducted with the additives as they would occur prior to actual use. The chemical and biological properties of fracturing effluent after it has been mixed and exposed to changes in pH and pressure remains unknown.

Table 43. TL_m Values of Fracturing Compounds[a]

Compound		TL_m[b]			
Name	Characteristics	4 hours	24 hours	48 hours	96 hours
Howco Suds	Non-ionic detergent	38 μg/mL	31 μg/mL	21 μg/mL	16 μg/mL
Morflow-II	Mixture of anionic & non-ionic detergents		27 μg/mL	18 μg/mL	13 μg/mL
Hai-50	Actylenic alcohols & cyclic amines			12 μg/mL	4.5 μg/mL
Pen-5	Non-ionic detergent	37 μg/mL	27 μg/mL	27 μg/mL	27 μg/mL
Wac-8	Talc & guar gum	Non-toxic to 10,000 μg/mL in 24 hours			
Wac-10	Talc, silica guar gum	Non-toxic to 10,000 μg/mL in 24 hours			
Fr-10	High molecular weight synthetic	Bioassay Method not applicable			
Fr-19	Polymer	Bioassay Method not applicable			

[a]Data from Borodczak (1968).

[b]TL_m = median toxicity levels.

Although the quantities of additives involved in well stimulation are not great and approximately half the material is recovered, the discharge of any spent fracturing fluid may create environmentally harmful conditions.

As part of the same Canadian study (Borodczak 1968), actual spent fracturing effluent was sampled during the flowback period. Concentrations of anionic detergents were initially low but increased to 75 μg/mL, and finally decreased to undetectable concentrations. These data indicate that the returning effluent will have variable composition and concentration over time. Therefore, biologically harmful conditions may occur at any time during the flowback period or not at all, depending on the concentrations of materials in the effluent and its dilution rate.

Release of Gas during Testing and Pressure Release during the Stimulation of a Well

Will the release of gaseous wastes from well stimulation impact air quality?

Natural gas and other gaseous emissions will be released to the atmosphere during various stages of the well fracturing process. The probable gaseous releases and resulting downwind concentrations are given in Table 44. Because of dispersion and the geographic location of the drilling facility (relative to shore), the concentration of the various releases will be negligible on shore.

Table 44. Gaseous Emissions[a] and Downwind Concentrations from Well Stimulation

Pollutant	Total Emissions, kg[b]	Concentration at 1000 m, μg/m^3
H_2S	10	11
Acid mist	1	1

[a]Other gaseous emissions may include nitrogen and CO_2 both of which are nontoxic gases.

[b]To convert kg to lb, multiply by 2.2046.

WASTE DISPOSAL

Disposal of Drilling-Related Wastes

What requirements are there for the disposal of wastes associated with drilling operations?

Under the 1972 amendments to the Federal Water Pollution Control Act (Pub. L. No. 92-500, 86 Stat. 816, 33 USC § 1251 *et seq*), the Environmental Protection Agency is required to formulate effluent guidelines for materials discharged into the nation's waters (33 USC § 1311). These guidelines and state water quality standards are applied to individual point source discharges through the NPDES program (33 USC § 1342). Each of the three states (Ohio, Pennsylvania, and New York) has been granted the authority to administer this program (see section on Clean Water Act).

Final effluent limitation guidelines for the oil and gas extraction industry, although proposed, have not been promulgated. At this time, the

Great Lakes are in the process of being transferred from the onshore to the coastal subcategory (Horvatin 1978--personal communication). The limitations which will then apply are given in Table 25. Stricter guidelines are under consideration for this category in other areas of the country (Hill 1978--personal communication).

Since Lake Erie is a major source of drinking water for the surrounding communities, the states have also taken steps to protect this natural resource. Under the FWPCA, as amended by the Clean Water Act (Pub. L. No. 95-217, 33 USC § 1251 *et seq*), state NPDES limits must be at least as strict as those established by EPA [33 USC § 1342 (b)(1)]. State laws and regulations establish water quality classifications for each body of water in the state [N.Y. Environ. Conserv. Law § 17-0101 *et seq* (McKinney); 6 N.Y. Codes, Rules, & Reg. §§ 700-04, 835-39; 35 Pa. Cons. Stat. Ann. § 691.1 *et seq* (Purdon); 25 Pa. Code § 91 *et seq*]. Discharges that cause the water quality to fall below the established standard are not permitted.

In addition to the outlined permitting authority, the states can control effluents through their leasing program or drilling regulations. Appropriate state agencies may determine that effluents otherwise allowed to be discharged must be contained for treatment or land disposal. For example, Pennsylvania's proposed lease requires that all potential effluents be brought to shore (Pa. Dep. Environ. Resour. 1977a, 1977b).

Discharges to the Lake are also governed by the 1972 Water Quality Agreement between the United States and Canada which established general water quality objectives for the Great Lakes system ["Agreement Between the United States of America and Canada on Great Lakes Water Quality," 23 U.S.T. 301, T.I.A.S. No. 7312 (1972)]. More exact standards regarding certain pollutants have since been developed. A second agreement, seeking to upgrade the quality of the Great Lakes, is being worked on and may be signed this year (1978). It will be implemented through modifications in existing federal and state programs.

Multiple options are available to dispose of wastes that are brought to shore, including reinjections in approved disposal wells, treatment by an approved sewage plant, or burial at an approved landfill. (The Safe Drinking Water Act, 42 USC § 300f *et seq* may be applied to injection operations.) All these states have land-based gas drilling programs, and regulations have been established for waste disposal. Even so, the states may wish to create a separate regulatory program to govern the disposal of wastes from the Lake.

Disposal of Chemical Wastes

What disposal procedures might be used to handle chemical wastes produced during U.S. drilling activities on Lake Erie?

Gas well drilling involves injecting a slurry of drilling muds (generally bentonite clays plus additives) into the well, and withdrawing the rock cuttings along with the injected material. By operating in the closed-cycle mode, all material returned from the well can be contained on the drilling rig. To the extent feasible, the drilling muds will be reclaimed on board for reuse in subsequent drilling. When the muds are no longer useful, waste disposal problems arise because the drilling mud additives may include potentially

toxic or hazardous substances. Natural contaminants, including brines, oil-bearing materials, and pyritic minerals, may be returned to the drilling rig from the wellbore along with rock cuttings during closed-cycle operations. These materials may also have potentially adverse impacts on biota if released to the Lake.

Other wastes produced during gas development activities are those produced during well stimulation. Materials such as acids, gels, surfactants, sands, and gases are injected into the well under pressure. Following stimulation operations, much of the material injected into the desired production strata will return to the surface under pressure along with produced waters (brines). The materials used during well stimulation have a broad range of potential toxicities.

Based on the Canadian experience, drilling and fracturing will produce about 90 m^3 (0.07 acre-ft) of wastes per well. These are collected and transported to shore for disposal at approved industrial waste disposal sites. We are predicting a drilling rate of 225 wells per year including dry wells (based on scenario presented in Appendix A). Assuming that all dry wells are stimulated, annual waste production will be about 20,000 m^3 (16 acre-ft). Thus the total waste production anticipated from development of Lake Erie natural gas will be approximately 440,000 m^3 (357 acre-ft) during the projected 22-year production period.

Disposal sites will have to be provided for the 440,000 m^3 (357 acre-ft) of wastes expected to be produced by the drilling and stimulation operations required to fully develop the Lake Erie resources. Two alternative disposal methods will be considered here: shallow well injection and surface disposal in ponds.

Shallow well injection has been tried in Canada, using existing dry wells onshore. But because operating costs are too high compared to available alternatives the trend has been to move away from injection disposal. Since we cannot assume the same regulatory environment for the U.S. side of the Lake as is present on the Canadian side, the costs of alternative disposal methods may be higher and thus shallow well injection may be cost competitive in the United States. The capacity of existing dry wells to accept the wastes generated by developing USLE gas development activities has not yet been explored. The great number of abandoned and improperly sealed wells in the region pose an additional problem. Should any abandoned wells have hydrologic contact with the disposal well, injection of wastes into the disposal well could deliver contaminants to the surface via the leaking, abandoned wellbore.

Determination of the ultimate role that well injection may play in USLE gas development activities must await more complete evaluation of geological and technological feasibility in addition to interpretations of existing and forthcoming state and federal injection well regulations. A preliminary examination of the suitability for using Lake Erie watershed geologic formations for gas well waste injection is presented on pp. 108-112.

Surface disposal in ponds will require 440×10^3 m^3 (357 acre-ft) total capacity for all drilling, including dry wells, for the life of the project. By comparison, a 1000 megawatt (MW) coal-fired power plant would produce 730×10^3 m^3 (590 acre-ft) of fly ash slurry each year (Dvorak et al. 1977).

Similarly, a typical uranium mill is expected to produce 620×10^3 m^3 (500 acre-ft) of tailings slurry per year, of which 330×10^3 m^3 (270 acre-ft) of water will be decanted, leaving 290×10^3 m^3 (235 acre-ft) of tailings added to the disposal site each year (U.S. Nuclear Regulatory Commission 1977). Thus the total (22-year) waste production resulting from Lake Erie natural gas development is comparable to the annual waste production from a single coal-fired power plant or one typical uranium mill. Although the exact composition of the wastes generated by drilling is not presently available, it is reasonably clear that disposal into ordinary landfills will not be acceptable. The probable disposal method used will be dewatering (e.g., by pond sedimentation, vacuum filtration, centrifugation, or combinations of these methods), and disposal into lined (impervious liner) and capped (impervious cap) landfills or ponds. These methods are presently in use for disposal of residuals generated by coal and uranium fuel cycles. It should be noted that the alternate fuel cycle residues pose generically similar disposal problems as those resulting from natural gas development (Table 45).

Table 45. Problems Posed by Alternate Fuel Cycle Residues

Residual	Fuel Type	Problems
Fly ash	Coal	Trace elements Sulfites, sulfates Acid Thizotropic (tends to become fluid when disturbed)
Tailings	Uranium	Trace elements Acid or alkaline Radionuclides
Drilling and fracing wastes	Gas	Trace elements Acid Surfactants and lubricants

Historically, a number of disposal alternatives have been used. These include: combination with asphalt for road construction (has been used for U.S. land-based drilling wastes) and use as a road-wetting agent to control fugitive dust (has been used in Canada for Lake Erie-based drilling wastes).

TRANSPORTATION OF MATERIALS TO AND FROM DRILLING SITE

Construction of New Port Facilities

Would increased lake traffic resulting from USLE gas development activities require new or expanded port facilities?

Port facilities must be located on navigable waters. For Lake Erie, then, these facilities are essentially restricted to the shoreland zone. Water depths in the port areas must obviously be greater than the fully laden draft of the vessels for which the port is designed. At the same time, all dockside structures should be above the probable maximum height of storm waves or seiches. Invariably, this will require considerable site preparation, including shoreline dredging and construction of building and dockage foundations.

The amount of earthmoving required to construct port facilities can be minimized by siting the facilities in areas with favorable topography. Table 46 lists examples of Lake Erie shoreland topographies and their suitability for port facilities. The cited suggestions for providing sufficient dockage assume new facility construction. However, from both an economic and an environmental point of view, expansion of existing port facilities would be a preferable alternative.

Table 46. Suitability of Lake Erie Shoreland Topographies as Port Facilities

Type of Topography	Suitability as a Port	Comments
Bay	Excellent	Minimum dredging, moderate cut and fill, all fill supplied from onsite (cut and dredge spoil).
River mouth	Excellent	Moderate dredging, minimum cut and fill, all fill supplied from onsite.
Floodplain	Moderate[a]	High dredging, moderate cut and fill, excess fill and spoils produced onsite.
Wetlands	Moderate[a] to poor	Moderate to high dredging, high fill, offsite source of fill required.
Shale bluff	Unsuited	High dredging, high cutting, large excess fill and spoils produced onsite.

[a]The regulatory climate is such that this area should be rated as poor (Pub. L. 92-500 § 404).

In order to estimate the land requirements for port facilities in support of any U.S. drilling activities, we have taken a conservative, analytical approach. Assuming ten rigs in operation during the 180-day drilling season, supported by one shore-to-rig trip per day per rig for movement of supplies and personnel, there will be approximately 1800 dockages attributable to drilling per season. Compared to the waterborne commerce records (Corps of Engineers 1977) for ships coming into harbors in Lake Erie during 1976 (Table 47), ship movements attributable to the development of Lake Erie gas resources may account for as much as a 10 percent increase in dockages. Existing port facilities should be able to absorb this increased shipping. Therefore, no new or expanded port facilities will be required to support gas drilling in Lake Erie.

Table 47. Inbound Ship Traffic for Lake Erie Harbors, 1976[a]

Harbor	Passenger and Dry Cargo	Tanker	Towboats, Tugboats	*Barges* Dry Cargo	*Barges* Tanker	Total
Monroe, Mich.	323	0	2	2	0	327
Toledo, Ohio	2,861	92	406	325	77	3,761
Sandusky, Ohio	5,394	0	0	0	0	5,394
Huron, Ohio	981	0	0	0	0	981
Lorain, Ohio	1,386	11	5	0	5	1,407
Cleveland, Ohio	1,701	31	22	7	30	1,791
Fairport, Ohio	528	0	0	0	0	528
Ashtabula, Ohio	775	0	0	0	0	775
Conneaut, Ohio	1,163	0	5	3	0	1,171
Erie, Pa.	1,318	19	6	0	2	1,345
Buffalo, N.Y.	735	135	35	1	23	929
Totals	17,165	288	481	338	137	18,409

[a]Source: U.S. Corps of Engineers (1977).

The projected 1800 shore-to-rig trips per season will require no more than two tugboat-sized work-boats* per rig to transport personnel and routine supplies. The entire fleet thus will require ten rigs, four stimulation

*Often modified tugboats.

barges, twenty work-boats and four tugboats. The four tugboats can be assumed to come from existing ships. Thus the fleet of ships required to support a maximum amount of drilling consists of ten rigs, four barges, and twenty small ships. Existing off-season storage should be able to accommodate these vessels.

Finally Greenwood (1978) lists five major drydock facilities in Lake Erie. This is presumed to be sufficient to handle maintenance of the Lake Erie gas development fleet.

Therefore no shoreland acreage would be expected to be committed to port facilities to support USLE gas production.

PLUGGING AND ABANDONING THE WELL

Liquid Hydrocarbon Recovery from Lake Erie Wells

How much liquid hydrocarbon might be permitted from an offshore gas well before drilling operations must cease and the well be plugged?

Each of the three states bordering Lake Erie (Ohio, Pennsylvania, and New York) gives a general definition of oil and gas in its laws or regulations. Pennsylvania's is typical of all three. Oil is defined as follows: "Crude petroleum oil and all other hydrocarbons regardless of gravity produced at a well in liquid form by ordinary production methods but does not include liquid hydrocarbons which were originally in a gaseous phase in the reservoir." Gas is "[a]ll natural gas and other volatile hydrocarbons not herein defined as oil, including condensate" (25 Pa. Code § 79.1). None of the states attempt to classify returns containing both oil and gas.

The amount of liquid hydrocarbon recovery that will be permitted from Lake Erie gas wells is a matter left to the discretion of the states.

New York

New York legislation requires that drilling operations cease immediately if there is evidence suggesting "the presence of liquid hydrocarbons" [N.Y. Environ. Conserv. Law § 23-1101 (McKinney, Supp. 1977)]. In such cases a formation test is to be conducted in the presence of a representative of the Department of Environmental Conservation (DEC). The wellbore must be permanently plugged if the test shows "appreciable" liquid hydrocarbons.

In its report to the legislature, DEC was more specific. The well is to be plugged and abandoned if the formation test indicates a production potential of five gallons or more a day. With a production potential of less than five gallons a day, drilling may resume after an intermediate string of casing is set (New York State Dep. Environ. Conser. 1977). It is not specified whether this five gallons includes condensates or not. This report did little more than suggest regulations that might be promulgated and had no official status.

Pennsylvania

The Pennsylvania draft lease agreement requires that all wells encountering oil, condensate,* or wet gas** be plugged or that those zones capable of producing the same be cemented off (Pa. Draft Lease § 1.1).

Ohio

Drafts for leasing agreements or special regulations regarding Lake Erie have not been developed.

Ontario

Ontario's regulations require production licenses to be surrendered to the government in areas that have been "proven to reasonably contain oil." Notwithstanding this provision, the license may be retained for the purpose of exploring for gas above the strata from which oil was recovered.

LANDFALL

Bringing of Pipelines from the Lake onto Shore and Nearshore Area

Would the landfall of pipelines from underwater collection systems require large commitments of shore and nearshore habitats? What environmental impacts would be associated with these landfalls?

Lake Erie natural gas would be collected into 10 to 20 cm (4 to 8 in.) pipelines and then brought on shore. Approximately ten to fifty such lines would be required to produce the USLE resources. A more accurate prediction of the number of collection lines cannot be made without information concerning the geometry of the producing wells within the fields. The lower value (10 lines) assumes that the producing wells will be clustered, while the higher value (50 lines) assumes random locations for the producing wells.

The number of landfalls constructed would be less than or equal to the number of 10 to 20 cm (4.0 to 8.0 in.) collection lines, again depending upon the geometry of the producing wells within the fields, and upon the geographic relationships among the fields. To the extent that the fields are clustered, the lines can share landfalls. Similarly, if clusters of producing wells are grouped, the collection lines from the clusters of wells can share a landfall. For the remainder of this section, it is assumed that ten to twenty landfalls will be sufficient to handle the ten to fifty pipelines required to transport the produced Lake Erie gas resources.

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*A natural gas liquid with a low vapor pressure, compared with natural gasoline and liquid petroleum gas.

**A gas dissolved in heavier hydrocarbons. Natural gas is said to be wet when it contains > 1135 L (300 gal) of propane, butane, and other liquid hydrocarbons per thousand cubic feet.

Landfalls may be laid either above or below ground. Although the Canadian experience includes above-ground landfalls, it is assumed that all U.S. construction will be of the below-ground type. The primary advantage of the below-ground landfall is protection against ice-scouring damage to the pipeline. In particular, the buried landfall is less susceptible to pipeline rupture, its attendant safety problems, and the resulting loss of resources. An unrelated advantage of buried landfalls is the virtual absence of aesthetic impacts.

Several routing strategies may be used to bring the produced gas from the lake to the compressor stations: (1) across wetlands; (2) up major rivers and creeks, or their floodplains; (3) up small streams or their valleys; or (4) across upland routes.

Wetlands would probably be avoided as sensitive areas. These areas are generally valued as wildlife habitats and for their aesthetic values. They are also subject to control as part of coastal zone planning activities and of the permitting responsibilities of COE (Pub. L 95-217 § 404). There are only three major wetlands along the U.S. shore of Lake Erie from Sandusky Bay, Ohio, to Buffalo, New York; one extending eastward from Sandusky Bay, one at Presque Isle, and the other west of the Grand River at Mentor Marsh.

It seems safe to predict that the major rivers and creeks will also be avoided. Most of the rivers have heavily developed harbors at their mouths and are surrounded by active port cities. Many major creeks also have small-craft harbors or towns. Therefore, there are safety reasons for avoiding these areas. There are 21 major rivers and creeks (Table 48) in the study region.

Table 48. Major Rivers and Creeks, Sandusky Bay, Ohio, to Buffalo River, New York

Sandusky River	Cowles Creek
Huron River	Ashtabula River
Vermilion River	Conneaut River
Beaver Creek	Elk Creek
Black River	Chautauga Creek
Cahoon Creek	Canadaway Creek
Rocky River	Walnut Creek-Silver Creek
Cuyahoga River	Cattaraugus Creek
Euclid Creek	Eighteen-Mile Creek
Chagrin River	Buffalo River
Grand River	

Either of the two remaining landforms (stream valleys and uplands) may be suitable for the onshore portion of the collection system. However, much of the upland shore type rises abruptly above the beach as shale bluffs. These areas are less desirable for right of ways (ROWs) from an engineering point of view. Although it is feasible to auger through these bluffs, subsequent access to the pipelines for maintenance would be difficult. On the other hand, construction and ROW maintenance in the stream valleys would be less desirable from an environmental point of view. Water quality in the streams could be adversely affected by siltation and/or herbicides from ROW maintenance operations. Furthermore, direct construction damage to streambeds may adversely affect the aquatic biota of the stream or even preempt breeding areas for Lake Erie fisheries. None of these problems poses insurmountable obstacles to pipeline construction, but they do suggest constraints on construction practices. The ultimate routing decisions should be based on site specific benefit-cost analyses with equal attention to several viable alternative routes.

Construction of the landfalls will require surface disturbance to cut the trench in which the pipelines will be buried. The trench required for pipes up to the expected 20 cm (8 in.) can be dug with a tractor-mounted wheel-type or continuous-belt trencher. Additional equipment for welding, laying the pipe, and backfilling the trench will have to be operated adjacent to the trench. Assuming a 10- to 20-m (33- to 66-ft) wide disturbance per landfall, the total disturbance per landfall will be 100 to 400 m (330 to 1300 ft). Even if fifty separate landfalls were required, the maximum disturbance would be 1000 m (3300 ft).

The Lake Erie shoreline from Cedar Point, Ohio, to the lighthouse on the south side of Buffalo, New York, is approximately 385 km (239 mi) long excluding bays and inlets at river mouths. Therefore, the total disturbance due to the construction of landfalls is expected to account for 0.03 to 0.1 percent of the shoreline. Even if each of the fifty projected collection pipelines required a separate landfall, which is unlikely, only 0.3 percent of the shoreline would be affected by construction. The impacts of committing this small amount of land to landfills would be minor for land use planning and for environmental or aesthetic concerns.

This analysis is based only upon the land that would be used for landfalls from offshore gas production. Further analysis will address the total commitment of shoreline by all users.

LAND FACILITIES

Construction and Operation of Compressor Stations and Backshore Pipelines

Would the construction and operation of land facilities require a large commitment of land? What environmental impacts on terrestrial habitats adjacent to the Lake can be anticipated as a result of constructing these facilities?

Gas pressures at the wellhead and in the underwater collection system are highly variable, but are expected to be on the order of magnitude of one megapascal (MPa) (150 psi). Major distribution pipelines normally operate at 3.4-5.5 MPa (500-800 psi). Hence, it is necessary to compress the gas before

feeding it into the distribution system. In addition, produced water and condensates must be removed; H_2S must be scrubbed out and mercaptans (odor) added. The scrubbed sulfur compounds are removed from the system and disposed of in an appropriate solid waste landfall.

After the produced natural gas reaches the shore (via the landfalls) it would be transported in 10 to 20 cm (4 to 8 in.) pipelines to the shore facilities. Based on the Canadian experience, these facilities would be sited as close to the landfall as feasible, generally 0.06 to 0.8 km (200 ft to 0.5 mi) inland. The shore facilities would require a 0.2 ha (0.5 acre) site for dewatering, condensate removal, scrubbing, compressing the gas, and for the associated parking lot.

The high pressure gas (3.4-5.5 MPa, or 500-800 psi) would be fed into the existing distribution system via 20 to 40 cm (8 to 16 in.) pipelines. Based on National Fuel Gas Distribution Corporation system maps (Becker 1978--personal communication), these high pressure feeder lines would generally not exceed 5 km (3 mi) in length.

A conservative analytical approach has been adopted to assess the potential impacts of piping on the land resources of the Lake Erie region. Hence, we assume: 50 landfalls (see Appendix A), each with a single 20 cm (8 in.) low-pressure pipeline; shore facilities set back a minimum distance of 0.06 km (200 ft) from the shore, and 41 cm (16 in.) high pressure feeder lines 5 km (3 mi) long.

Based on aerial photographs (Consumers Power Co. 1978), the nominal corridor width for a 40 cm (16 in.) pipeline is 16 m (22 ft). We can assume the same corridor width for the 20 cm (8 in.) land-based feeder pipeline. Thus, the entire 5 km (3 mi) long corridor would have an area of 8 ha (20 acres). Therefore, the total land committed to pipelines for producing Lake Erie gas resources would be 405 ha (1000 acres). In addition to the pipelines, there will be fifty shore facilities accounting for 10 ha (25 acres) of additional land committed to natural gas production. The total land required, then, for production of Lake Erie natural gas would be 415 ha (1020 acres).

The entire Lake Erie shoreline from Cedar Point, Ohio, to Buffalo, New York, is approximately 385 km (239 mi) long; the total Lake Erie shoreland within 5 km (3 mi) of the shoreline covers approximately 192,000 ha (475,000 acres). The land required for the production of Lake Erie natural gas represents 0.22 percent of this region.

Approximately one fifth of the above shoreland is in the coastal zone (40,000 ha, or 100,000 acres) defined by state coastal zone planning programs as that area of land within 1000 m (3280 ft) of the shoreline. About the same proportion of the pipeline corridors will also be in coastal zone areas (80 ha, or 200 acres). However, if we assume that all shore facilities will be within the coastal zone, the total commitment of coastal zone lands will be 91 ha (225 acres), or about 0.23 percent.

A commitment of 0.20 to 0.25 percent of the available land to natural gas development will have little or no impact on regional land resources. Even on a local basis, one pipeline and compressor station will require only 8 ha (20 acres).

Pipeline construction on land increases the risk of erosion due to the initial clearing of all vegetation from the ROW and to the surface disturbance caused by digging and backfilling the trench in which the pipe is buried. The area involved per pipeline (8 ha, or 20 acres) is approximately equal to a small farm field. Similarly, the amount of erosion is potentially equal to that from an eight-hectare plowed field. Since the regional climate is favorable for rapid vegetative stabilization of disturbed land surfaces, it is reasonable to expect that maximum exposure to erosion risk will be confined to a single growing season. While such risks should not be considered trivial, this will probably not increase erosion significantly.

Noise levels at the compressor site should be < 70 decibels (dBa) at the boundary (U.S. Dep. Energy 1978). Although this level is considered very noisy for residential areas (USEPA 1974), it is not expected that compressor facilities will be located within residential areas.

PROTECTION OF LAKE ERIE RESOURCES

Does the present legal framework adequately ensure protection of potable water supplies, aquatic life, and other resources from potential contaminant releases during drilling?

As discussed in "Obstructions to Navigation by Jack-up Rig or Drilling Ship," the federal government and the three state governments have broad authority to regulate actions that might impact water quality or aquatic life in those portions of the Lake under their jurisdiction. While current laws and regulations do not specifically regulate gas drilling in USLE, there are many federal and state statutes that regulate or allow the creation of new regulations to protect water quality and aquatic life (see Institutional Overview).

Expressed intentions of federal and state agencies, as well as current legislation, indicate that new legislation and regulations would probably be adopted if threats to water quality and aquatic life were perceived. However, timely implementation of appropriate regulations would be contingent upon early recognition and documentation of potential problems; examination of past drilling experience and research would be invaluable in this procedure.

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RESEARCH AND ANALYSIS

INTRODUCTION

The staff's review of literature and other information sources focused mainly upon economic initiatives for natural gas development, resource extraction technology, logistics of material* transport, the regulatory framework for drilling and production program management, environmental consequences of normal operations, and an accident spectrum basic to further evaluation of impact. Data needs were identified on the basis of the literature search and consultation with industry, government, and other information sources. The time required for meeting various data needs and the realities of the scheduling of field sampling on Lake Erie mandated a research program consisting of two complementary efforts.

The seasonal nature of the field sampling period on Lake Erie dictated that the initial research effort be directed toward specific project data needs and goals. These goals included the examination of 1) impacts resulting from releases of natural gas, oil, and brines of natural origin; 2) the effects of drilling and production discharges on water quality; and 3) the impact of drilling and production wastes on aquatic biota and potable water supplies. The research approach was prescribed by capabilities to acquire, or contract for, vessel time, manpower, and equipment appropriate to the specific project research needs. This was further complicated because the time of initiation of the project occurred after the period (January and February) during which most research vessel and equipment schedules are arranged for field season research on the Great Lakes.

The initial research consisted of a survey of light weight hydrocarbon gas concentrations and selected other parameters in the eastern and central basins of Lake Erie during September 1978.

The second research effort is complementary to the initial field and laboratory effort and also addresses other project goals and data needs. The staff will formulate and address specific questions on the biological and chemical impacts of operational or accidental discharges of materials from drilling, collection, and distribution phases of any U.S. Lake Erie drilling program. Based on the preliminary examination of issues, the nature of these questions will dictate at least one full field season of investigation. Considerable planning, in addition to that in progress, will be necessary to carry out confirmatory research that will supply supportive documentation for conclusions and recommendations included in the draft EIS.

The research described here must maintain a measure of flexibility suited to attainment of project goals in an environment of a rapidly changing data base. The experience and data of other researchers, in addition to that of

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*Material includes equipment and drilling supplies.

program participants, has been sought out and considered. At present, the staff believes that two research approaches described herein reflect the most fruitful approach to supply the data needs of the impact statement.

PHASE I: LAKE ERIE HYDROCARBON ANALYSIS

Field research initiated in Phase I has centered upon the measurement of background concentrations of light hydrocarbon gases in the lake water as an indication of total hydrocarbons in the eastern and central basins of Lake Erie. Data on concentrations of hydrocarbons are meager for Lake Erie (Ward 1977) and the other Great Lakes. The relative contributions of hydrocarbons from anthropogenic and natural sources have not been differentiated on a seasonal or source basis suitable for mass balance estimates comparable to those for other parameters such as chloride (Lam and Simons 1976) and phosphorus (Burns 1976). Information on contemporary concentrations of light hydrocarbons and total hydrocarbons was thus deemed to be crucial for evaluating the comparative contribution and environmental impact of offshore drilling on Lake Erie and for developing an efficient methodology for future assessments.

The release and dispersion of hydrocarbons in freshwater ecosystems is neither well documented nor well understood. The potential for hydrocarbon release to the Lake during the gas drilling process exists, should offshore drilling for gas be permitted in USLE. Assessment of the current extent of hydrocarbon pollution of Lake Erie is hampered by the lack of data needed to construct a budget of hydrocarbon loading to inshore and offshore waters from tributaries, naturally occurring seeps, and other sources.

Since Lake Erie is a source of potable water for numerous metropolitan areas as well as an important recreational and commercial resource, one important objective of the project is to investigate the present level of hydrocarbon contamination of Lake Erie waters.

Rationale

The decision to focus the initial field research program on measurement of contemporary concentrations of light hydrocarbons and total hydrocarbons in Lake Erie was based upon the following rationale:

1. Knowledge of the contemporary baseline concentrations of low-molecular weight and total hydrocarbons in Lake Erie and other Great Lakes would permit any future increase or decrease in hydrocarbon contamination to be substantiated.

    a. Data are needed to evaluate the impact that increased hydrocarbon loading may have on the potable water supply, recreation, and on commercial and sport fishing.

    b. Baseline data for hydrocarbon concentrations and effects are essential for developing guidelines on effluent limitations for offshore drilling for federal and state agencies in which NPDES authority has been delegated.

c. Data on ambient hydrocarbon concentrations are needed for comparative evaluation of the magnitude and importance of operational or accidental releases of hydrocarbons from sources such as pipeline leaks or ruptures, faulty well casing, wellhead damage, and blowouts.

d. If, as expected, concentrations of light and total hydrocarbons are highly correlated, measurement of light hydrocarbon levels using the procedure outlined below could be used for rapid estimation of total hydrocarbon levels in Lake Erie.

e. Turbulent mixing distributes the light hydrocarbon components of an input over much larger areas than is visible locally (spills, runoff sites, and seeps) and measurements of the individual gas components and certain of their ratios provide an indirect means for determining the source (geologic, biogenic, and/or anthropogenic) of hydrocarbon pollution.

2. The potential of natural gas, oil, and brine releases from sediments and/or fissures in Lake Erie needs to be established within the context of their magnitude, areal extent, and ecological significance.

   a. Use of the gas chromatographic (sniffer) system and auxiliary instrumentation will enhance capabilities for locating surface seeps of hydrocarbons or saline waters or other sources of geological origin.

   b. The short-interval, time-integrated measurements of hydrocarbon concentration, depth, temperature, current direction, conductivity, etc., should minimize problems of recurrent sampling of a given water mass. Definition of areas with abnormally high concentrations of total hydrocarbons will aid in determining the source and significance of hydrocarbons in these localized zones.

   c. Identification of areas with anomalous concentrations of hydrocarbons attributable to local oil spills, pipeline and wellhead discharges, municipal sewage, or river effluents may be identified and these inputs can be assessed relative to discharges that might accompany exploration, development, and production of natural gas.

3. The EIS on natural gas development in Lake Erie will include a map delineating areas of high and low environmental risk. Data gathered using the rapid sampling gas chromatograph (sniffer) system may provide insight into areas where precaution in drilling might be exercised on the presumption that the risk of accident could increase near areas of natural surface seeps.

   a. In areas where the source of hydrocarbon anomalies is believed to be of biogenic or anthropogenic origin, territory in which gas drilling otherwise might have been restricted (assuming drilling is permitted) can be reduced.

b. Known fissures or seeps can be further examined to determine if they are environmentally stressed areas; i.e., whether there are notable differences in biological communities that appear to reflect the influence of hydrocarbon release.

c. Potable water supplies located within areas of high hydrocarbon loading (aliphatic and polynuclear aromatic hydrocarbons) should be closely scrutinized for carcinogenic or mutagenic potential.

Research Approach

Minute quantities of low molecular weight hydrocarbons are dispersed and dissolved in Lake Erie; in some areas these hydrocarbons may form plumes which are transported by currents. These hydrocarbons can be detected at very low concentrations (5×10^{-9} mL gas/mL water).

The analytical equipment used in this study was developed by InterOcean Systems, Inc., San Diego, California. It employs a modified Beckman Process Gas Chromatograph with a flame ionization detector for determining the concentrations and forms of dissolved low molecular weight hydrocarbons in water pumped directly from the towed sonde.

The light hydrocarbon gases are continuously stripped from Lake Erie water by a vacuum produced by a booster pump with a restricted inflow. The stripped gases are injected every 190 seconds into two chromatographic columns for automatic analysis. Each column is designed to analyze three specific gases. Concentrations of methane, ethylene, ethane, propane, iso-butane, and normal butane are measured and automatically recorded on an almost continuous basis. Several additional parameters, i.e., conductivity, temperature, relative current speed and direction, and tow body depth are measured and recorded simultaneously. All data are recorded on a digital magnetic tape recorder, trend recorder, and analog chart. It is anticipated that a minimum of 12,000 measurements of light hydrocarbons, along with an equal number of determinations of supportive parameters, will be made during the survey.

Additional water samples, for a separate analysis of total hydrocarbons, will be collected in glass containers with aluminum-lined caps. Carbon tetrachloride (CCl_4) will be added to all samples to retard bacterial action and initiate extraction. The quantity of total extractable hydrocarbons in water sample extracts will be determined by an infrared method used by the Exxon Research and Engineering Company, Linden, N.J. (Huffman 1978--personal communication; Brown et al. 1976, 1978). These analyses will be performed when water samples are returned to the laboratory following conclusion of the field survey.

In situ measurements for conductivity, temperature, depth, pH, turbidity, and dissolved oxygen will be made in the eastern and central basins using an InterOcean Model 500 *in situ* Monitor System. The monitor system will be manually lowered into the water column at specific cruise locations. Based upon the previous day's data, locations will be selected to gain additional data on those parameters that affect the distribution and transport of hydrocarbon concentrations in Lake Erie.

The data and samples described above will be collected during a cruise (15-30 September 1978) aboard the Roger R. Simons in the central and eastern basins of Lake Erie. A cruise grid with ∿20 km (∿12 mi) spacing between transects will be followed (Figure 15).

Data collected during the field survey and subsequent laboratory analyses will require considerable organization and processing prior to interpretation. Several data reduction and processing procedures developed by InterOcean Systems, Inc., and extensively tested in other regions, will be employed to reduce raw data to a form suitable for further analysis. The number of individual time-integrated measurements of light hydrocarbons alone would be almost impossible to manage without a computerized methodology for integrating information about the concentration of six separate hydrocarbon parameters, sampling location and time, depth of sonde, and measurements of supportive parameters.

Once the preliminary data reduction procedures have been performed, and certain error terms identified, data relevant to Phase I goals can be organized and evaluated.

Expected Results

Results of this study will certainly assist in addressing the validity of several assumptions and hypotheses concerning potential sources and mechanisms of hydrocarbon loading to the Lake. Since there is a paucity of information pertaining to the total and/or light hydrocarbon concentrations in the Lake itself, results of this study should provide a useful extension of current knowledge on the hydrocarbon characteristics of Lake Erie specifically and of the Laurentian Great Lakes system more generally.

Data from the Phase I research program will be used to prepare concentration contour maps of low molecular weight hydrocarbons for areas surveyed. Concentration contour maps (or other forms of graphic display of data) may permit delineation of areas of high hydrocarbon concentration with respect to the location of potable water supply intakes, recreation areas, and commercial or sport fishing grounds. These maps, or other graphics, should also be helpful in displaying areas of natural gas, oil, and/or brine releases attributable to potentially different sources (e.g., sediments, seeps). Definition of spatial variations in hydrocarbon concentrations in the Lake, even if only for a portion of one season, should provide a highly useful data base for further examination of environmental consequences of offshore drilling and development of natural gas resources in USLE. Because the relative ratios of low molecular weight hydrocarbons can be used to identify gross differences in the form of hydrocarbon pollution (e.g., natural seeps or anthropogenic discharges), these ratios may provide a rapid index for identifying origin of hydrocarbon contaminants in the Lake. Extractions of total hydrocarbons hopefully will provide data useful in evaluating the potential hydrocarbon contribution from municipal and industrial sources.

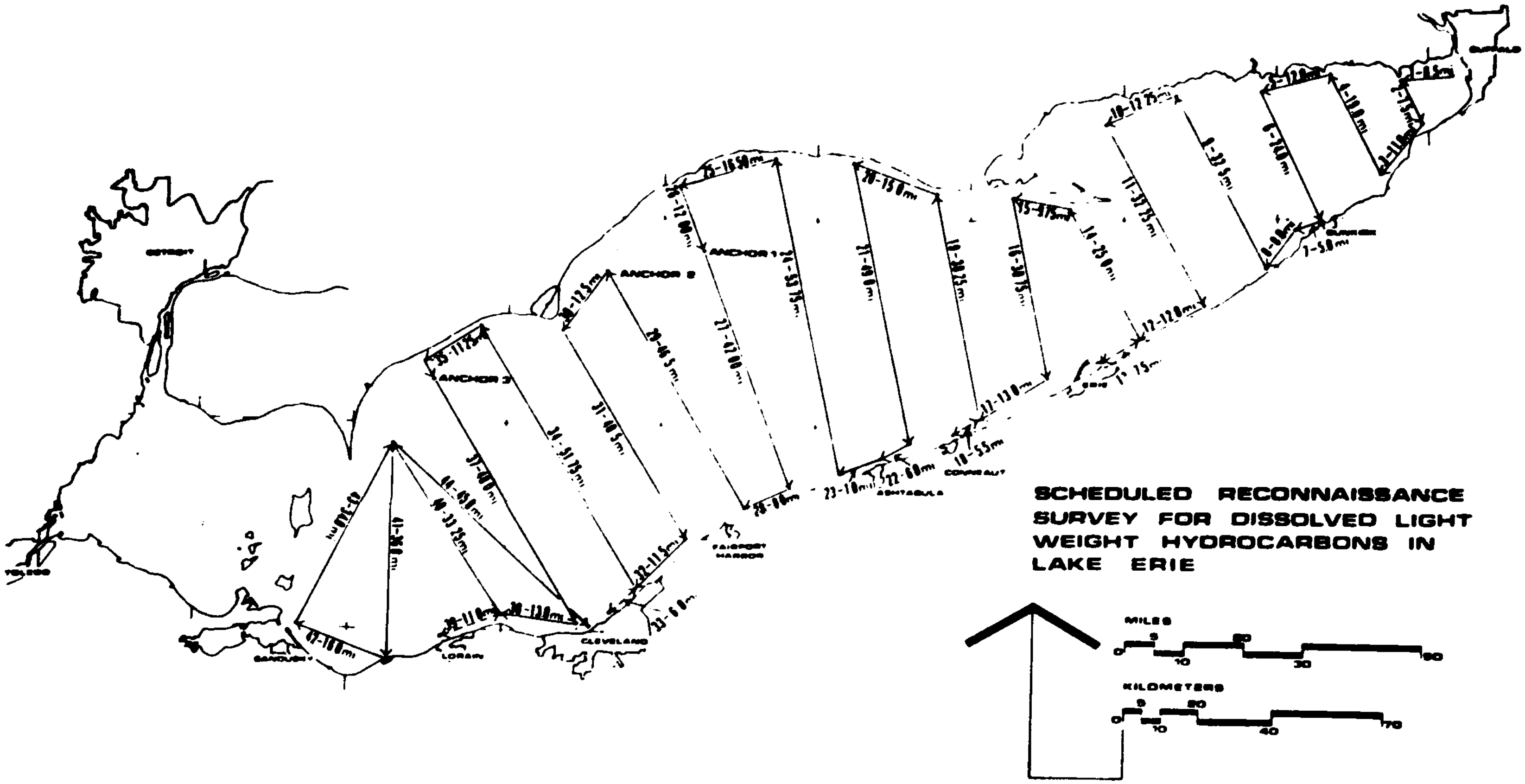

Figure 15. Scheduled Reconnaissance Survey for Dissolved Light Weight Hydrocarbons in Lake Erie. The numbers on each line represent the transect followed by mileage.

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PROPOSED PHASE II RESEARCH

Characterization of Drilling Effluents and Their Impacts on Water Quality and Biota

The fate of some drilling wastes produced in USLE is uncertain. Discharge of unspecified amounts of drilling cuttings and muds, fracturing compounds, and contaminants from the drillhole to the water column during normal operation or accident events poses a potential danger of impact to water quality and biota. Because of legislative and administrative constraints that could be imposed on drilling operations and possible modification of regulatory procedures by litigation, the potential environmental impacts of open- and closed-cycle drilling and ancillary activities must be considered. The potential impact of unavoidable releases such as sediment disturbance will also receive further attention.

While some data on contaminant loading during offshore drilling operations may be found in the literature, such data are scarce and are currently insufficient to adequately assess the water quality and biotic impacts.

The Phase I research program, to determine the spatial distribution and concentration of low molecular weight and total hydrocarbons and other parameters in the water (see p. 172) will be complemented by research proposed for Phase II. Phase II research will include:

1. Observations of ongoing drilling and fracturing operations on an offshore rig and barge to determine the types of discharges from the operations.

2. Discharge sampling for mass balance determinations of contaminant loading rates and chemical characterization of drilling and fracturing compounds after use.

3. Determination of the spatial and temporal distribution of contaminants in the discharge plume, light extinction profiles, current speeds, water temperature, and other supplemental parameters appropriate for describing discharge plume dynamics. Measurement techniques will utilize nephalometry and transmittometry (turbidity determinations), gas chromatography and atomic absorption spectroscopy (concentrations of low molecular weight hydrocarbons and metals, respectively), and other standard chemical analysis techniques. The emphasis of the plume dynamics studies will be to delineate the amount of Lake area and volume affected by contaminants attributable to drilling operations and to determine the distance such contaminants may be transported.

   The Phase II research program will include modeling studies (see next section) for evaluation of plume behavior under conditions (seasonal, event) other than those encountered in field programs.

4. *In situ* bioassays in the vicinity of a well during drilling and fracturing operations. Potential areas of investigation include: bioaccumulation of contaminants, behavioral and sublethal responses.

Completion of much of the Phase II research will require sampling of materials used or generated during the drilling process, sampling in the vicinity of an ongoing drilling and fracturing operation, and, in some cases, utilization of data that must be supplied by the drilling company. Thus, attainment of many of the research goals outlined will be contingent upon the cooperation of a company conducting offshore drilling in Lake Erie or other appropriate freshwater environment.

Modeling

Water quality, biotic, and other impacts resulting from the introduction of contaminants into a water body depend on many factors including the chemical and physical properties of the contaminant, the amount and rate of release, mixing properties of the water body, and the extent of transport. The mixing and transport properties of the water body, in turn, depend upon such factors as temperature structure; basin morphology; and climatic conditions, particularly wind stress.

Analysis of the impacts of contaminant loading or other modifications to a water body are often greatly aided by the use of mathematical models which take into account many interacting factors in order to predict the response to a given stress.

A wide variety of models has been developed to permit quantitative analysis of issues in the Great Lakes. Many of these have been summarized in the reviews by Hydroscience (1973) and Lorenzen et al. (1974), and an extensive literature exists documenting more recent work. Included are circulation and mixing models which calculate the response of lake current patterns and mixing properties to meteorological conditions, models which calculate transport of chemical substances by currents, plume models which calculate water temperature distribution in the vicinity of a thermal outfall or concentration of chemicals or pathogenic organisms in the vicinity of a point-loading source, water level models which relate elevation of the lake surface to water inflows and outflows, ice and lake-wide water temperature models, eutrophication models, models which calculate concentrations of a given contaminant anticipated in various components of a food chain, models which calculate dissolved oxygen concentrations in lakewater, fishery models, wave height models, and a model which examines economic impacts of shoreline erosion.

Available models are being reviewed to determine their applicability to estimating the magnitudes of potential impacts of contaminant releases resulting from drilling for natural gas in Lake Erie. Such releases may be the result of either normal drilling operations or accidents. Models are being examined with respect to relevance of the issues addressed, magnitude of the anticipated effects, and the degree of confidence in the model. Emerging as models of possible interest are those which describe short distance transport of contaminant plumes and those which simulate large-scale lake circulation patterns.

Releases of suspended sediments, drill cuttings, drilling muds, cement, and fracturing compounds from normal drilling of a single well are expected to be small. It is anticipated that large-scale lake circulation models will not be directly applicable to analysis of the dispersion of these effluents and of small-scale accidental releases because of the local nature of the probable

effects. At best, such large-scale models could be used to provide estimates of anticipated current speeds where such data are currently lacking. A more appropriate approach to analysis of contaminant dispersion from such small-scale sources would be the use of local transport or plume models. Large-scale lake circulation models are more likely to be useful for analysis of transport of contaminants from large-scale sources such as one might postulate for some accidents.

Contaminant Transport

Contaminant transport mechanisms in lakes, current patterns in Lake Erie, and availability of models for simulating local and large-scale transport in large lakes are summarized in the following discussion.

Transport mechanisms. Movement of a substance introduced into a lake is influenced by a wide variety of factors including the properties of the substance and the transport and mixing properties of the water body. Those substances which are not subject to removal by chemical or physical processes and which, therefore, retain their identity for extended periods of time in a water body are commonly called *conservative*. They represent the simplest contaminants under discussion, since their transport is influenced only by the mixing properties of the water body.

If a single quantity of a conservative substance is introduced into a lake as an instantaneous injection, the resultant cloud of material may be transported by bulk motion of lakewater, a process known as bulk transport or advection. The contaminant cloud may also grow in size because of turbulent diffusion and dispersion. Turbulent diffusion refers to the mixing of water parcels with surrounding water by irregular, random motions present during turbulence. By comparison, molecular diffusion rates are small and may be ignored. Distortion and enlargement of the cloud by differential bulk movements is called dispersion. As the cloud enlarges, the concentration of the contaminant decreases until it eventually becomes indistinguishable from the main water mass. Boundaries such as coastlines and the lake surface or bottom, and the presence of density gradients such as the thermocline of a thermally stratified lake may limit dilution of the contaminant (Csanady 1975).

Density differences between the contaminant and the water body will influence spatial distribution; contaminants will rise or sink depending on their specific gravity as compared with that of water.

Distribution of nonconservative substances may be further influenced by chemical changes, biological uptake or release, and settling out of the water column.

Current patterns in Lake Erie. Wind-induced currents are a major factor in determining circulation patterns of large lakes. These currents are modified by thermally driven currents caused by differential heating and cooling of the water mass. The wind-driven circulation pattern of a lake depends upon wind direction, speed, and duration; upon shoreline configuration and lake bottom topography; latitude; and lake thermal structure. Consequently, lake circulation patterns may change seasonally, as well as on a day-to-day basis. Current speeds and directions may also change with water depth. Nearshore

currents are constrained to be parallel to shore, while midlake circulation patterns may vary widely in direction and in speed.

Current patterns in Lake Erie vary with season, wind stress, and depth. Long-term current patterns in Lake Erie have been measured in numerous studies and summarized by Hamblin (1971). A brief discussion of Lake Erie currents appears in the Lake Erie Overview section of this report.

Lake Circulation Models

Knowledge of the range of current speeds and directions expected at given lake locations is important to the investigation of the behavior of effluent plumes and to determination of the possible ultimate fate of contaminants. Data exist on general long-term circulation patterns in Lake Erie. Current speeds and directions may change greatly and rapidly in response to variations in wind stress, and current patterns at any given time may bear little or no resemblance to the long-term trends. Short-term current data for a wide range of wind conditions do not exist for most locations in Lake Erie.

Numerous models, developed for investigation of Great Lakes circulation under specified wind stresses, are emerging as useful tools in investigating current speeds and directions. A physical model has been used to investigate current patterns and pollutant transport in Lake Erie (Buechi and Rumer 1969, Howell et al. 1970), and numerical models exist which use adaptations of Platzman's (1963) techniques to simulate the dynamics of lake response to wind stress. Many of these models have been reviewed by Cheng et al. (1976) and by Lick (1976). Such models have been used to model general circulation patterns in Lake Erie (Simons 1976, Sheng and Lick in review), and to determine the effects of large in-lake structures on currents and contaminant dispersion (Sheng 1975).

These models may be used to simulate short-term lake current responses to a wide range of wind stresses as well as long-term current patterns; they also facilitate investigation of pollutant transport under a range of anticipated conditions.

Plume Models

A wide variety of models is available for analysis of the movement of contaminants introduced into a water body either as a single pulse or in a continuous stream. These range from analytical models of the diffusion of a cloud of some conservative substance introduced as a single pulse (Csanady 1975) to much more detailed digital models of instantaneous or continuous introduction of sludges consisting of liquid and solid phases (Koh and Chang 1973). The latter model simulates movement of wastes disposed of by dumping, discharge through a nozzle, and discharge into a barge wake. Phenomena considered include differential settling of particles of differing sizes, convective descent of the wastes, dynamic collapse (vertical collapse and horizontal spreading of a cloud when it reaches a neutrally buoyant position in the water column), mixing with ambient water, and bottom encounter.

Cultural Resources Analysis

Investigation of the feasibility of gas production in the U.S. portion of Lake Erie requires consideration of the various environmental and cultural impacts that could result from the proposed action. The cultural and environmental evaluations should include assessment of impacts to the prehistoric and historic cultural resources of the area. Locating and evaluating cultural resources is a requirement of federal programs and is stipulated by several federal laws. Moreover, many states now have programs aimed at locating and protecting prehistoric and historic sites.

Purpose

The purpose of this section is to suggest a feasible program for generating guidelines to be used in the location and evaluation of prehistoric and historic sites and in the mitigation of impacts to these sites. These guidelines are intended to be applied to submerged cultural resources on the lake bottom as well as to those located on the lakeshore where pipelines and support facilities might be constructed. Any study that is actually initiated will of course require concurrence of COE, EPA, the Interagency Archeological Service, and the Advisory Council for Historic Preservation.

More specifically, the suggested program is intended to identify and rank order areas of Lake Erie bottom and shoreline according to their probability for resource occurrence or discoverability. After areas have been ranked by degree of sensitivity for cultural resources, they will be tied to specific guidelines detailing procedures that must be used for specific site survey of specific individual lease tracts. Further recommendations on how these guidelines should be implemented and enforced will also be developed.

Approach

The following studies will be recommended in order to identify and rank areas according to degree of archeological significance and develop procedures for cultural resource management for potential lease areas assigned to each class. Such studies, probably limited to secondary sources of data, could serve to:

1. Review and evaluate existing knowledge concerning the local geomorphology since the Late Wisconsin Glaciation. These data would be used to determine water depths and potential terrestial habitats that may now be submerged.

2. Identify and map major sailing-ship routes, battle areas, ports, and known locations of shipwrecks and to relate all data to known ship technology.

3. Identify and map known prehistoric sites and compile data on settlement-subsistence systems for the local area.

4. Correlate historic and prehistoric site function to topographic-environmental settings over time.

5. Delineate data deficiencies.

6. Rank areas by potential for cultural resources in select locational type.

7. Review currently available methods for site survey and evaluation.

8. Develop survey guidelines for different areas having varying degrees of cultural resource sensitivity.

Data Collection

Information to be collected for this project would be from published and unpublished sources. From these secondary sources, data would be collected in three major subject areas: geomorphology/environment, prehistoric occupation, and historic occupation and shipping.

Geomorphology/environment. From the Late Wisconsin Glaciation to recent times, the geology of the area should be synthesized in order to characterize the major geological features and events. This would include the history of local topographic features that may have affected, or been affected by, prehistoric and historic peoples using this area over time. Brief attention should also be given to the relationship between changing geomorphologic features and the local flora and fauna that may have been important to human exploitation of the Lake and shore zones.

Prehistoric occupation. The cultural sequence of the local area would be described from the earliest known occupation until the historic era began (circa A.D. 1600). This characterization would be cultural-historical and would emphasize the changing social, economic, political, and techno-environmental components of local cultural systems. Depending on the kinds of data available, diagnostic material evidence would be related to specific cultural components and functional settlement types.

Historic occupation and shipping. Historic use of the area would be documented, including types of ships from the time of colonial exploration through World War II. Ships and historic sites would be reviewed as they relate to discoverability. This would include a systematic study of historical reports on shipwrecks for this study-period.

Analysis

There would be a three-stage analysis. In Stage One, field data should be analyzed for correlations between prehistoric and historic activities. Data permitting, weighting factors would be assigned to different kinds of topographic features as to the probability of their containing cultural resources of specific types and age. This part of the study would also be important for identifying major research problems and data deficiencies.

In State Two, methods for locating submerged, buried, and surface cultural resources would be reviewed. Specific methods would then be related to their suitability for discovering the kinds of resources and topographic associations determined during Stage One of the analysis.

In Stage Three, problems such as data deficiencies and method limitations would be reviewed. Suggestions for future research would be made at this time.

Results

A major expected result of this kind of study presupposing the existence of sufficient data, would be the development of maps to: locate known resources, rank designated areas as to their potential for having undiscovered cultural resources, and identify areas for which information is unavailable and where probabilities for resources cannot be determined.

Another result would appear as a set of guidelines outlining survey and resource evaluation programs for different areas as defined on the suggested maps. These guidelines would be accompanied by suggested procedures for implementation and monitoring of the various programs.

Public Involvement

As the country's energy position has become more serious and complex, the conflict between society's values of environmental protection and economic growth has become more acute. Congress, as well as private groups and individuals, have begun to re-examine their position on environmental matters where these matters interfere with or impede the production or transmission of energy.

It is possible that this trend has also occurred with regard to the development of the gas under Lake Erie. Only a decade ago, this country, along with Canada, began a concerted effort to reverse the environmental decline in the condition of the Great Lakes, particularly Lake Erie. Recent announcements have been made that this effort has begun to produce the positive results intended. Yet, during this same period, the states surrounding Lake Erie have experienced several of the harshest winters in recent history. Severe weather conditions during the winter of 1976-1977 caused an energy shortage for many communities in these states. Lack of fuel and supply-related increases in prices economically impacted these communities, many of which were already suffering from economic stagnation or decline.

The need for identifying local public opinion on the development of gas under Lake Erie has been identified as an important task by all parties associated with the project. Now that the project staff has examined certain issues relating to offshore drilling technology, laws and regulations, environmental matters, and the economics of developing gas under the Lake, it is prepared to recommend a mechanism of public interaction. Phase II would be an appropriate time to initiate this process. Data from this social research would provide the most current information necessary for preparation of the environmental impact statement.

It is proposed that a three-stage approach be undertaken to obtain the necessary information. Described broadly, the first stage would allow the staff to identify appropriate social resource experts for involvement in the study. In-depth interviews with interested parties would be undertaken during the second term. These interviews could be followed by a random telephone survey of people residing around the Lake. The intention of such an approach would be to understand the issues and concerns of both the interest groups, which have had a chance to study the problem and formulate an opinion, and the general public, which might be affected by the development of Lake Erie gas.

During the first stage of this research, we propose to work closely with the Great Lakes Basin Commission (GLBC) to identify interest groups and issues that should be explored. Ms. Lee Botts, chairperson of GLBC, has been contacted and has expressed her interest in assisting us in promoting public involvement. Also, records of public meetings concerning Lake Erie gas development and pollution abatement could be gathered and analyzed to increase our knowledge of interested parties and issues.

Although the number of interested groups cannot be determined at this time, it is our intention to contact all such parties and to pursue in-depth interviews with appropriate group representatives. Questionnaires could be designed to obtain an understanding of individual groups' viewpoints on the potential advantages and disadvantages of Lake Erie gas development. The questionnaire would be designed to identify information that would help decision-makers effectively determine the fate of the proposed gas development program. If the number of interest groups is too large to allow personal interviews, a decision would be made to select an interview sample.

The information obtained from the second phase could assist in the design of the telephone questionnaire. A random sample of approximately 500 to 1,000 people could be selected from residents of the counties bordering Lake Erie. An effort should be made to determine if the general public is aware of the potential for developing Lake gas, if they have concerns about such activity, if these concerns are similar to those expressed by public interest groups, and how their views are affected by economic and environmental concerns.

A number of research institutes, contacted to perform this research, have declined due to time and contract limitations. Ultimately, it will be necessary to work with an experienced and qualified research survey organization in order to accomplish the discussed goals. The following time schedule outlines the time required for the planned activities:

	Months					
	1	2	3	4	5	6
Phase One						
Phase Two						
Phase Three						
Data Analysis						

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APPENDIX A. PRODUCTION SCENARIO FOR EXPLOITATION OF U.S. LAKE ERIE NATURAL GAS RESOURCES

INTRODUCTION

In any attempt to predict future events (and this is certainly the case for exploitation of natural gas resources underlying the U.S. side of Lake Erie), the predictor should rely heavily on any previous experience available. The only experience in drilling on the U.S. side of Lake Erie consists of two wells drilled off the Pennsylvania Lake Erie coast, both of which were dry holes.

On the Canadian side of the Lake, there is a great amount of experience. Drilling started in Lake Erie (Canada) in 1913 and was intermittent until 1956. Forty-three wells were drilled during this period; over 1000 have been drilled since. The Canadian program has resulted in total production of 31.2 billion m^3 (114 BCF) for a period beginning in 1913 and extending through 1977 (Hurd and Kingston 1978). The average annual production since 1971 has been 158.6 million m^3 (5.6 BCF) from 300 producing wells [an average of 510,000 m^3 (18 MMCF) per well per year]. One-hundred-thirty additional wells, already drilled, can be made productive by hookup to lakebed gathering pipelines.

Economically exploitable resources are assumed in this section for the purpose of evaluating economic consequences of gas production. Canadian gas reserves underlying Lake Erie (reserves are quantities that can be produced with present technology and at present costs plus inflation) are estimated to be 5.1 billion m^3 (180 BCF). This is a 30-year supply at current production rates. Total Canadian Lake Erie resources are conservatively estimated to be about 28.3 billion m^3 (1000 BCF) (Hurd and Kingston 1978). These latter values include the reserves and other resources which will require new technology and which will probably incur higher costs for production.

The scenario chosen and discussed herein for the future development and production of the natural gas resources underneath USLE follows closely the Canadian experience which was described in some detail by Hurd and Kingston (1978). The authors outlined current drilling and pipeline construction methods used to explore and produce natural gas entrapped within the Clinton formations in the central basin of Lake Erie. The historical development of an area of approximately 1000 km^2 (400 mi^2) was examined, and costs associated with its drilling and production were broadly outlined. In the description of the scenario which follows, this 400-square-mile area is called a "block."

The scenario presented envisions simultaneous development of the central and eastern basins of the U.S. side of Lake Erie. Three states (Ohio, Pennsylvania, and New York) border these lake basins. The areas of the lake surface extending from the state borders is shown in Table A.1 (central and eastern basins only), as is the number of "blocks" within each state area.

Table A.1. Surface Areas of the Eastern and Central Basins of Lake Erie that Extend from the Borders of New York, Ohio, and Pennsylvania

State	Acres[a]	Square Miles[a,b]	Blocks[c]	State % of USLE Total
Ohio	∿ 1,700,000	2,660	7	66.6
Pennsylvania	480,180	750	2	18.8
New York	373,500	580	1	14.6
Total (3 states)	2,553,680	3,990	10	100.0
Total for U.S. Lake Erie		5,000		
Total Lake Erie (incl. Canada)		9,940		

[a]To convert acres to hectares, multiply by 0.4047; to convert square miles to square kilometers, multiply by 2.59.

[b]Amount of total area estimated to be involved in production of natural gas.

[c]Approximately 400 square miles per block. A block is an area set up for exploration, development, and production.

ASSUMPTIONS

Many of the assumptions used to define this scenario were based on the Canadian Lake Erie drilling experience. The scenario is designed so that drilling occurs at a rapid rate during a concentrated time period, thus serving as a foundation for worst-case analysis of environmental impacts.

Some overlapping of blocks at state boundaries is assumed to occur. It is assumed that nine blocks are explored and developed, and production is obtained from them. Since those explored might not all be productive, the areas first explored might not be the same as the ones finally hooked up to pipelines for production. Wells drilled in nonproductive block areas are considered part of the 35 percent dry hole production for the entire Lake and account for the lower than 65 percent productive wells in the first few years. Other assumptions used to develop the costs presented follow.

This scenario was designed without economic or institutional constraints. It was designed to demonstrate the effects of extracting a maximum of recoverable resources [estimated to be between 15.1 billion m^3 (533 BCF) and 25.1 billion m^3 (888 BCF)] over the span of time between 1979 and 2000 (see Table A.4). The scenario also provides a basis for estimating costs that might accrue during gas development and production.

Other assumptions used to develop the costs are:

1. Nine rigs start exploration. A tenth rig is added after 15 years of production. This allows more wells to be drilled so that annual USLE gas production can be maintained despite decreased production of wells drilled during the beginning of the production period. Decreased production of older wells results from reservoir depletion after approximately 15 years.

2. Annually, each rig can drill 25 wells per 6-month drilling season. Maximum drilling production from each rig is reached in the third year after start.

3. The success ratio is 65 percent.

4. Two assumptions for average well production rates are shown. Whereas both the United States (New York State) and Canada assume a 15-year life for producing wells, each assumes different declining production rates for their estimates of average production for the lifetime of each well [cf. New York State Energy Office (1977) and Hurd and Kingston (1978)]. Canadian production per well is said to be 850,000 m^3 (30 MMCF) per year [2300 m^3 (82 MCF) per day], whereas New York estimates are based on 510,000 m^3 (18 MMCF) per year [1400 m^3 (50 MCF) per day]. However, since 1971 average actual production from Canadian wells has been closer to 510,000 m^3 (18 MMCF) than 850,000 m^3 (30 MMCF) per year. The total predicted costs attributed to developing and producing USLE natural gas are based on one *drilling* rate that results in the development of 2309 producing wells after 22 years. These are fixed costs to the developer industry. The cost per unit volume of gas produced will vary based on the assumed well production rates. Therefore, more gas produced at *a fixed cost of 22 years* will result in a lower unit cost. Although the scenario demonstrates the effects of two well production rates and hence two average unit costs of gas produced, current Canadian experience indicates that average well production rates are toward the low end of the predicted USLE range. Therefore, predicted average unit costs of produced gas could be close to the high end of the unit cost range (see Table A.5).

5. The estimates are based on 1978 U.S. dollars. Exploration and development for production are assumed to have begun. The twenty-second year of production will be the year 2000.

6. The underlying costs for drilling, fracturing, plugging, maintenance, and bringing gas onshore are listed in Table A.2 for productive and dry wells.

7. Annual maintenance costs for producing wells were assumed to be $0.25 per 28.3 m^3 (1 MCF) produced (Hurd and Kingston 1978).

8. Royalties were assumed to be 5 percent of the sum of all drilling and plugging costs and maintenance. There is a discussion in Hurd and Kingston (1978) of how royalties are handled in relation to taxes. In Canada, legislative provisions permit the operator to reduce royalties (using lease-rental payments and a pipeline write-off formula) to not less than 5 percent of the wellhead value of the gas. Canadian operators use these provisions to the fullest.

Table A.2. Costs for Productive and Dry Wells[a]

	Producing Well		
	Dollars	% of Total	Dry Hole
Rig operation	64,000	30	52,000
Third party	40,000	18	12,000
Well stimulation (fracing)[b]	23,000	11	-
Rig capitalization[c]	24,000	11	24,000
Underwater collection system and shore facilities[b]	65,000	30	-
Total	216,000	100	88,000

[a]In 1978 U.S. dollars.

[b]Includes capital cost.

[c]Based on Table 25-36, "Amortization," from Perry and Chilton (1973). Original rig cost $5,500,000; amortization period is 21 years.

9. Assumptions for the numbers of persons involved in drilling, fracing, indirect (third party) effort, maintenance, and pipeline construction and laying were made so that estimates of the total labor force involved in the exploitation scenario could be developed. These estimates are summarized in Table A.3 and are based on the following numbers:

a. Crew per drilling rig--30 persons.

b. Crew per well-stimulation barge--10 persons.

c. Maintenance and third party--20 persons per 113 million m^3 (4 BCF) produced plus a maximum of 200 persons for maintenance of the entire system at full production. This is about one person for every ten wells.

d. For the construction and laying of the gathering and onshore pipeline, a crew of 300-400 persons would be employed annually. This group would be working at three to six locations along the lakeshore at one time and would include the labor for construction, pipe laying, and manning of an onshore compressor station. There would be 40-60 such stations located along the U.S. shoreline of the Lake between Sandusky, Ohio, and Buffalo, New York.

SUMMARY

The exploitation costs for the scenario are developed from the data presented in Table A.4. The labor force required is shown in Table A.3. The important information from Table A.4 is summarized in Table A.5.

Table A.3. Labor Force Required to Implement Lake Erie Gas Development

Year	Year No.	Annual Gas Production (BCF)[a,b]	Persons Employed Annually: Drilling	Persons Employed Annually: Fracing	Persons Employed Annually: Maintenance & Third Party[c]	Persons Employed Annually: Total	Onshore Hookups Required[d]: Annual	Onshore Hookups Required[d]: Cumulative	Persons Employed Annually for Pipeline Construction[d,e]	Grand Total of Persons Employed Annually
1979	1	0.5	270	10	15	295	0	-	60	355
1980	2	1.5	270	20	30	320	2	2	100	420
1981	3	3.5	270	30	45	345	0	2	120	565
1982	4	6.1	270	40	60	370	3	5	180	570
1983	5	8.7	270	40	135	445	3	8	240	685
1984	6	11.4	270	40	200	510	3	11	300	810
1985	7	14	270	40	225	535	3	14	360	895
1986	8	16.6	270	40	250	560	3	17	360	920
1987	9	19.3	270	40	300	610	3	20	360	970
1988	10	21.9	270	40	300	610	3	23	360	970
1989	11	24.5	270	40	300	610	3	26	360	970
1990	12	27.1	270	40	300	610	3	29	360	970
1991	13	29.8	270	40	300	610	3	32	360	970
1992	14	32.4	270	40	300	610	3	35	360	970
1993	15	35	270	40	300	610	3	38	360	970
1994	16	37.4	300	40	300	640	3	41	400	1040
1995	17	39.4	300	40	300	640	3	44	400	1040
1996	18	40.4	300	40	300	640	3	47	400	1040
1997	19	40.6	300	40	300	640	3	50	400	1040
1998	20	41	300	40	300	640	3	53	400	1040
1999	21	41.2	300	40	300	640	3	56	400	1040
2000	22	41.4	300	40	300	640	3	59	400	1040

[a] To convert cubic feet to cubic meters, multiply by 0.02832.

[b] Annual gas production @ 18 MMCF per well.

[c] Ten third-party persons per rig after the fourth year; ten maintenance persons per 4 BCF (50% of $0.25/MCF is maintenance labor charge).

[d] In units of 50 wells.

[e] Including onshore hookups.

Abbreviations: MCF = thousands of cubic feet; MMCF = millions of cubic feet; BCF = billions of cubic feet.

Table A.4. Data Base for Maximum Exploitation of U.S. Lake Erie Natural Gas Resources

Year	Year No.	No. of Rigs	No. of Wells Drilled Each Year	No. of Drilled Wells Producing Each Year	No. of Wells Plugged due to Low Prod.[a]	Dry Holes Formed Each Year	Cumulative No. of Wells Producing Each Year	Natural Gas Produced (BCF) @ 30 MMCF per Well per Year Annual	Natural Gas Produced (BCF) @ 30 MMCF per Well per Year Total	Natural Gas Produced (BCF) @ 18 MMCF per Well per Year Annual	Natural Gas Produced (BCF) @ 18 MMCF per Well per Year Total
1979	1	9	135	27	-	108	27	0.8	0.8	0.5	0.5
1980	2	9	180	54	-	126	81	2.4	3.2	1.5	1.9
1981	3	9	225	113	-	112	194	5.8	9	3.5	5.4
1982	4	9	225	146	-	79	340	10.2	19.2	6.1	11.6
1983	5	9	225	146	-	79	486	14.6	33.8	8.7	20.3
1984	6	9	225	146	-	79	632	19	52.8	11.4	31.7
1985	7	9	225	146	-	79	778	23	75.8	14	45.7
1986	8	9	225	146	-	79	924	28	104	16.6	62.3
1987	9	9	225	146	-	79	1070	32	136	19.3	81.6
1988	10	9	225	146	-	79	1216	36.5	172.3	21.9	103.5
1989	11	9	225	146	-	79	1362	40.8	213	24.5	128
1990	12	9	225	146	-	79	1508	45.2	258	27.1	155
1991	13	9	225	146	-	79	1654	49.6	308	29.8	185
1992	14	9	225	146	-	79	1800	54	362	32.4	217.3
1993	15	9	225	146	-	79	1946	58.4	420	35	252
1994	16	10	250	163	27	87	2082	62.5	483	37.4	290
1995	17	10	250	163	54	87	2191	65.7	548	39.4	329
1996	18	10	250	163	113	87	2242	67.3	616	40.4	370
1997	19	10	250	163	146	87	2258	67.7	684	40.6	410
1998	20	10	250	163	146	87	2275	68	752	41	451
1999	21	10	250	163	146	87	2292	68	820	41.2	492
2000	22	10	250	163	146	87	2309	68	888	41.4	533

Table A.4. (Continued)

Year	Year No.	Drilling Cost (10^6 U.S. dollars) — Annual Cost: Producing Wells	Annual Cost: Dry Holes	Annual Cost: Plugged Wells	Annual Cost: Total Cost	Cumulated Cost	Other Costs (10^6 U.S. dollars) — Annual Maintenance @ $0.25/MCF: b	Annual Maintenance: c	Royalties @ 5% of Value: b	Royalties: c	Total Cost (10^6 U.S. dollars): Annual	Total Cost: Cumulated	Annual Cost (U.S. dollars/MCF): @ 30 MMCF per Well	@ 18 MMCF per Well
1979	1	5.8	9.5	0	15.3	15.3	0.2	0.1	0.8	0.8	16.3	16.3	21	33
1980	2	11.6	11.1	0	22.7	38	0.6	0.4	1.2	1.2	24.5	40.8	17	16
1981	3	24.4	9.8	0	34.2	72.2	1.4	0.9	1.8	1.8	37.4	78.2	6.40	11
1982	4	31.5	7.0	0	38.5	110.7	2.6	1.5	2.1	2.0	43.2	121.4	4.20	7
1983	5	31.5	7.0	0	38.5	149.2	3.6	2.2	2.1	2.0	44.2	165.6	3.00	5
1984	6	31.5	7.0	0	38.5	187.7	4.8	2.9	2.2	2.1	45.5	211	2.40	4
1985	7	31.5	7.0	0	38.5	226.2	5.8	3.5	2.2	2.1	46.5	258	2.00	3.30
1986	8	31.5	7.0	0	38.5	264.7	7	4.1	2.3	2.1	47.5	305	1.70	2.90
1987	9	31.5	7.0	0	38.5	303.2	8	4.8	2.3	2.2	48.8	354	1.50	2.50
1988	10	31.5	7.0	0	38.5	342	9.1	5.5	2.4	2.2	50	404	1.40	2.30
1989	11	31.5	7.0	0	38.5	380	10.2	6.1	2.4	2.2	51	455	1.25	2.10
1990	12	31.5	7.0	0	38.5	419	11.3	6.8	2.5	2.2	52	508	1.15	1.90
1991	13	31.5	7.0	0	38.5	457	12.4	7.5	2.5	2.3	53.4	561	1.07	1.80
1992	14	31.5	7.0	0	38.5	496	13.5	8.1	2.6	2.3	54.6	616	1.00	1.70
1993	15	31.5	7.0	0	38.5	534	14.6	8.8	2.6	2.4	56	671	0.96	1.60
1994	16	35.2	7.6	0.6	43	577	15.6	9.4	2.7	2.6	57	728	0.90	1.50
1995	17	35.2	7.6	1.2	44	621	16.4	9.8	2.7	2.6	58	786	0.88	1.50
1996	18	35.2	7.6	2.5	45	666	16.8	10.1	2.7	2.6	58	844	0.86	1.40
1997	19	35.2	7.6	3.2	46	712	16.9	10.2	2.8	2.6	58	902	0.85	1.40
1998	20	35.2	7.6	3.2	46	758	17	10.2	2.8	2.6	58	960	0.85	1.40
1999	21	35.2	7.6	3.2	46	804	17	10.3	2.8	2.6	58	1019	0.85	1.40
2000	22	35.2	7.6	3.2	46	850	17	10.4	2.8	2.7	58	1077	1.21[d]	2.02[e]

[a] Due to wells being more than 15 years old.

[b] For production rate of 30 MMCF per well per year.

[c] For production rate of 18 MMCF per well per year.

[d] Total cumulated cost (10^6 U.S. dollars)/total gas produced (BCF) @ 30 MMCF per well per year.

[e] Total cumulated cost (10^6 U.S. dollars)/total gas produced (BCF) @ 18 MMCF per well per year.

[f] To convert cubic feet to cubic meters, multiply by 0.02832.

Abbreviations: MCF = thousands of cubic feet; MMCF = millions of cubic feet; BCF = billions of cubic feet.

Table A.5. Summary of Cost Data per Well[a]

Costs	@ 18 MMCF[b] Annual Production	@ 30 MMCF[b] Annual Production
Total project costs ($$10^6$)	1,077	1,077
Total gas production (BCF)	533	888
Gas production per block (BCF)	∿ 60	∿ 100
Average cost of gas ($/MCF)	2.02	1.21

[a]In 1978 U.S. dollars.

[b]MMCF = millions of cubic feet. To convert cubic feet to cubic meters, multiply by 0.02832.

The average annual per-well production rates shown in Table A.4 result in very high unit costs [per 28.3 m^3 (1 MCF)] in the first ten years of well life (and project life) and low costs in the last ten years. Total (22-year) project costs divided by total (22-year) production are the data presented in Table A.5.

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